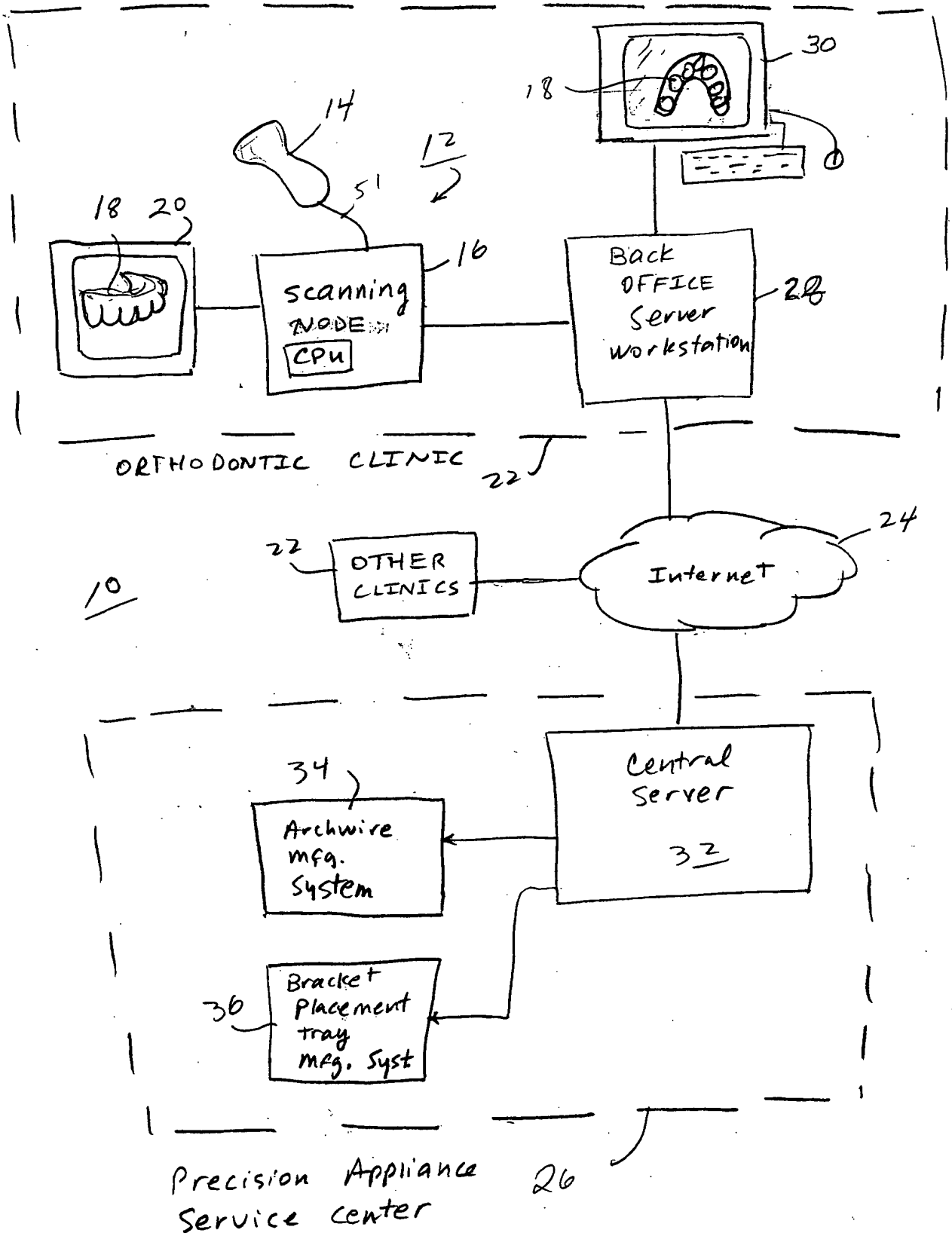

30
18
14
12
51
18
20
16
scanning
NODE
CPU
Back
OFFICE
Server
Workstation
28
ORTHODONTIC CLINIC
22
24
22
OTHER
CLINICS
Internet
10
34
Archwire
mfg.
System
Central
Server
32
36
Bracket
Placement
tray
mfg. Syst
Precision Appliance
Service center
26

Fig. 1

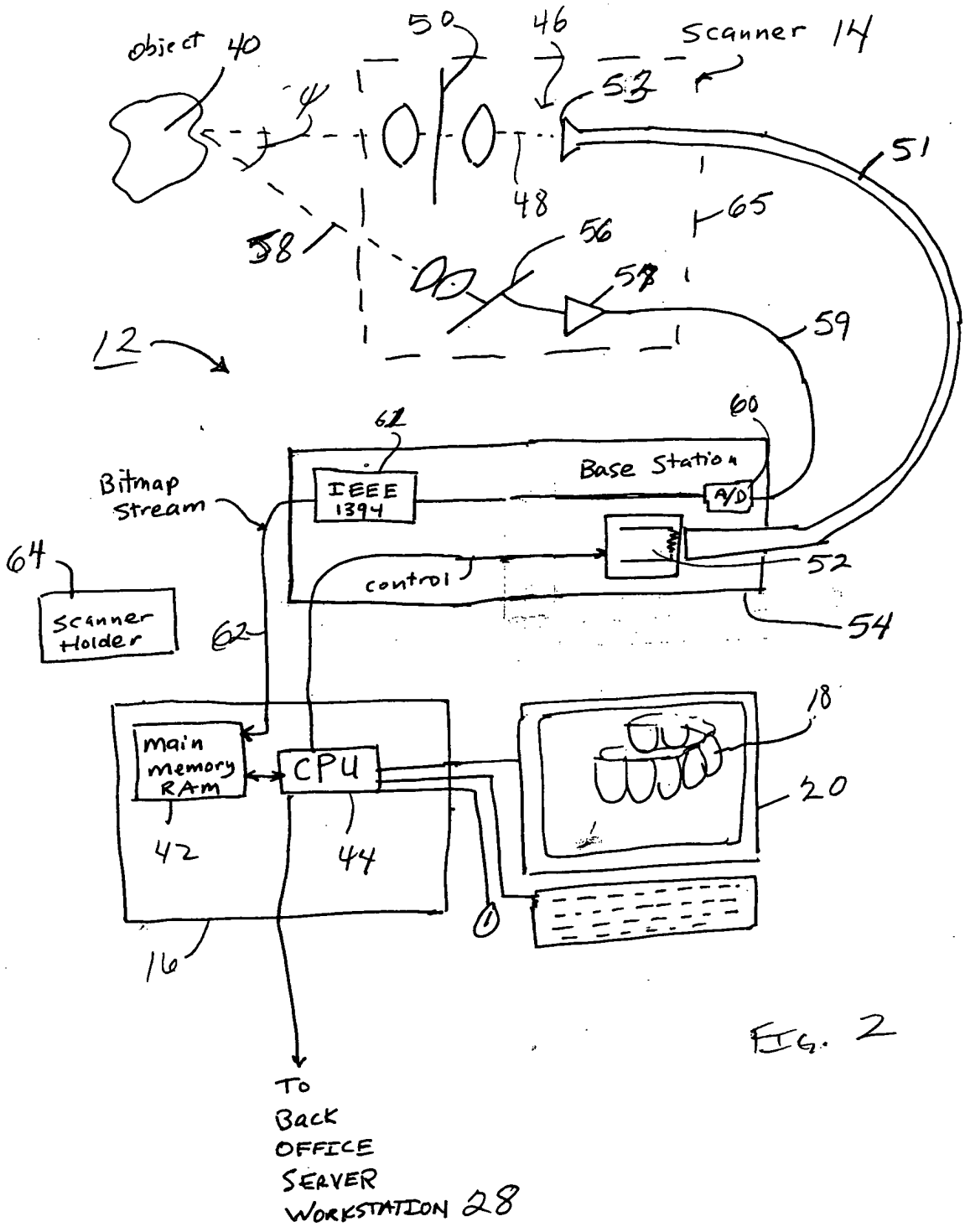

object 40
50
46
Scanner 14
53
51
48
65
58
56
57
59
12
60
62
Base Station
IEEE 1394
A/D
Bitmap Stream
64
control
52
Scanner Holder
62
54
18
main memory RAM
CPU
20
42
44
16
To Back OFFICE SERVER WORKSTATION 28

FIG. 2

Fig. 3

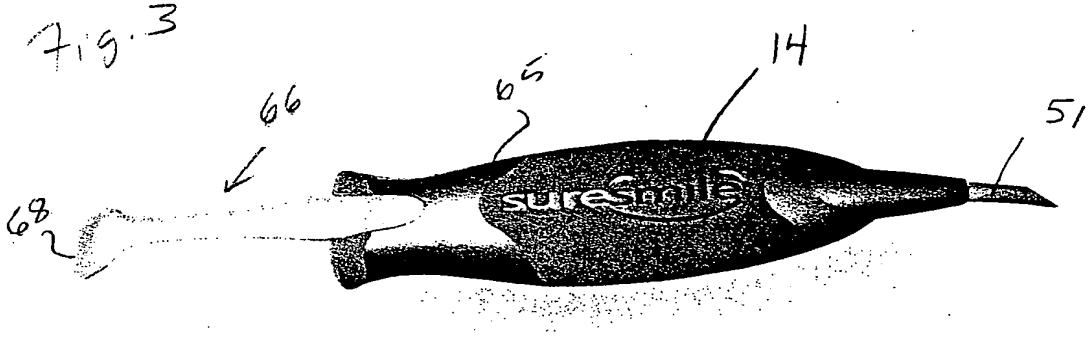
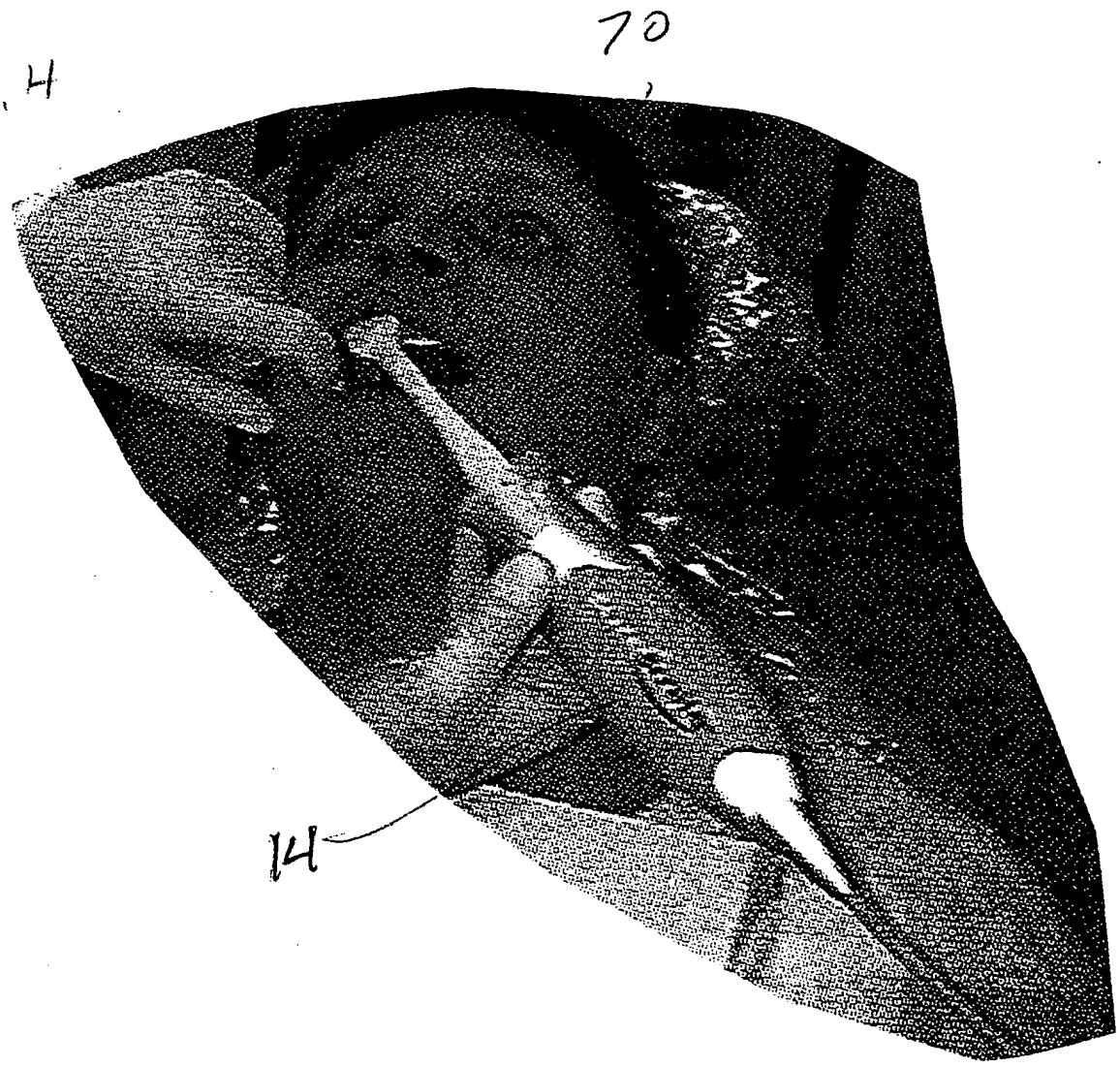


Fig. 4



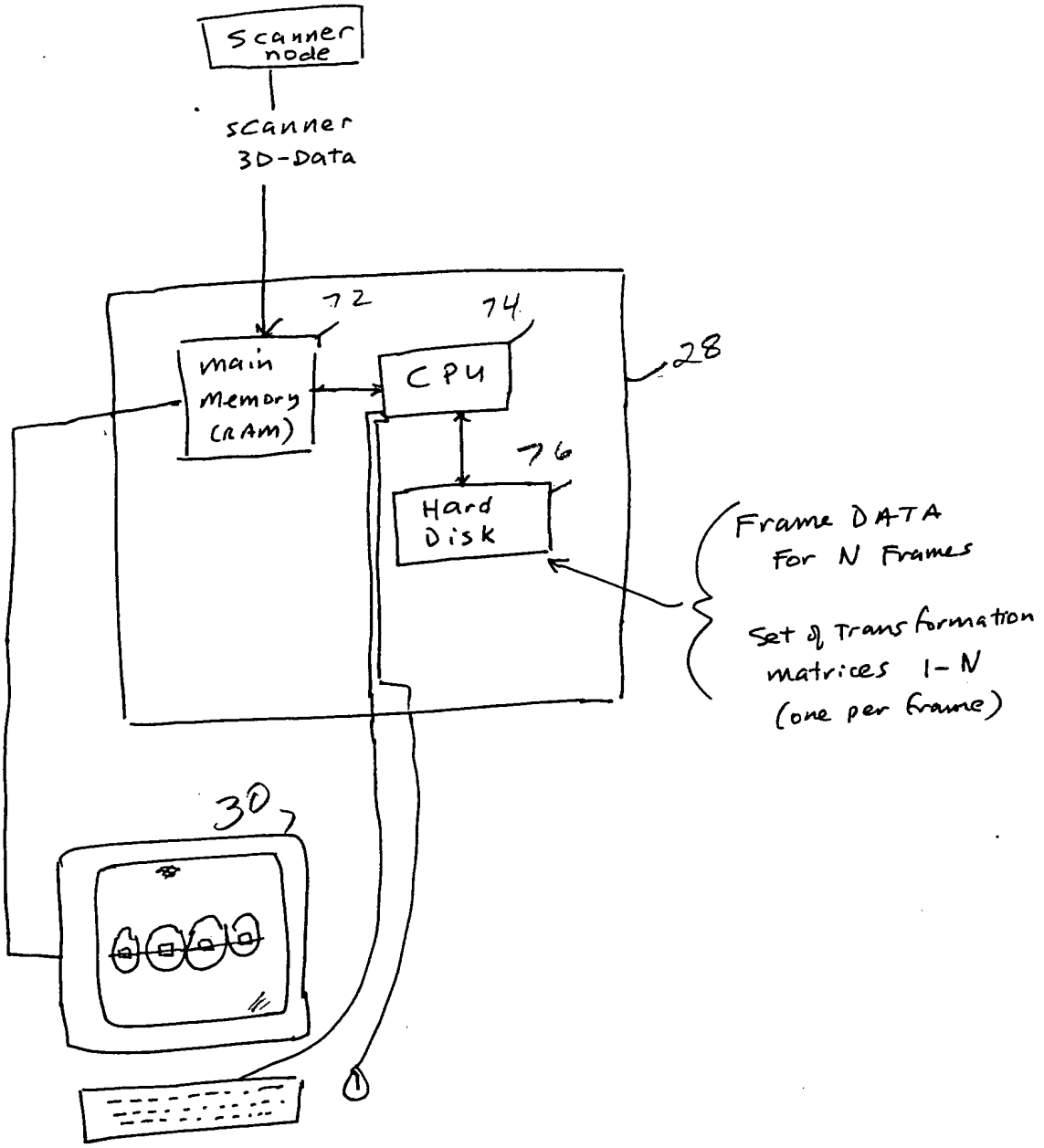

Scanner node
scanner 3D-Data
72
74
main Memory (RAM)
CPU
28
76
Hard Disk
Frame DATA For N Frames
Set of Transformation matrices 1-N (one per frame)
30

Fig. 5

3-Dimensional IMAGE capture
(per frame)

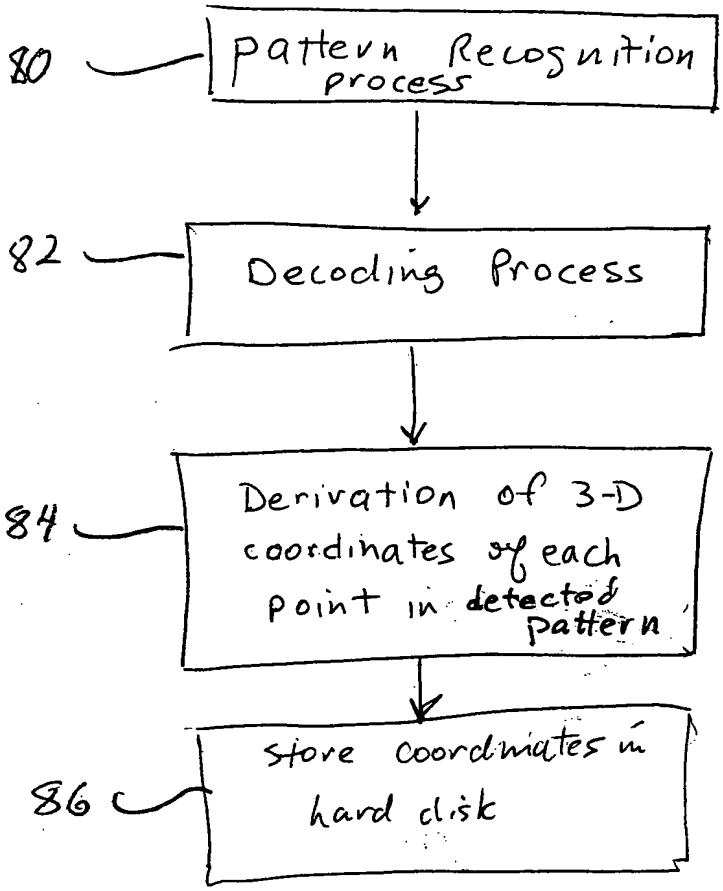


Fig. 6

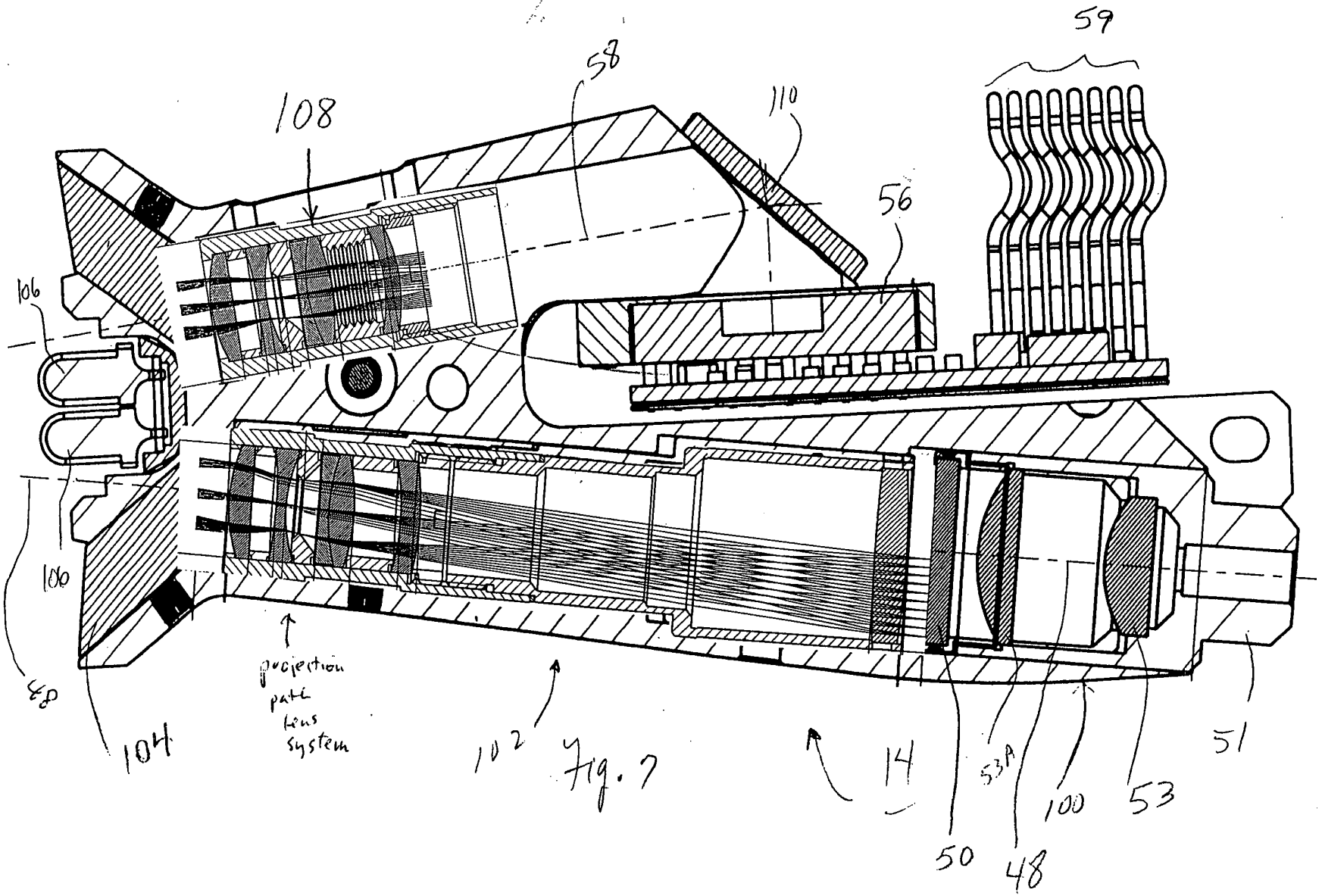
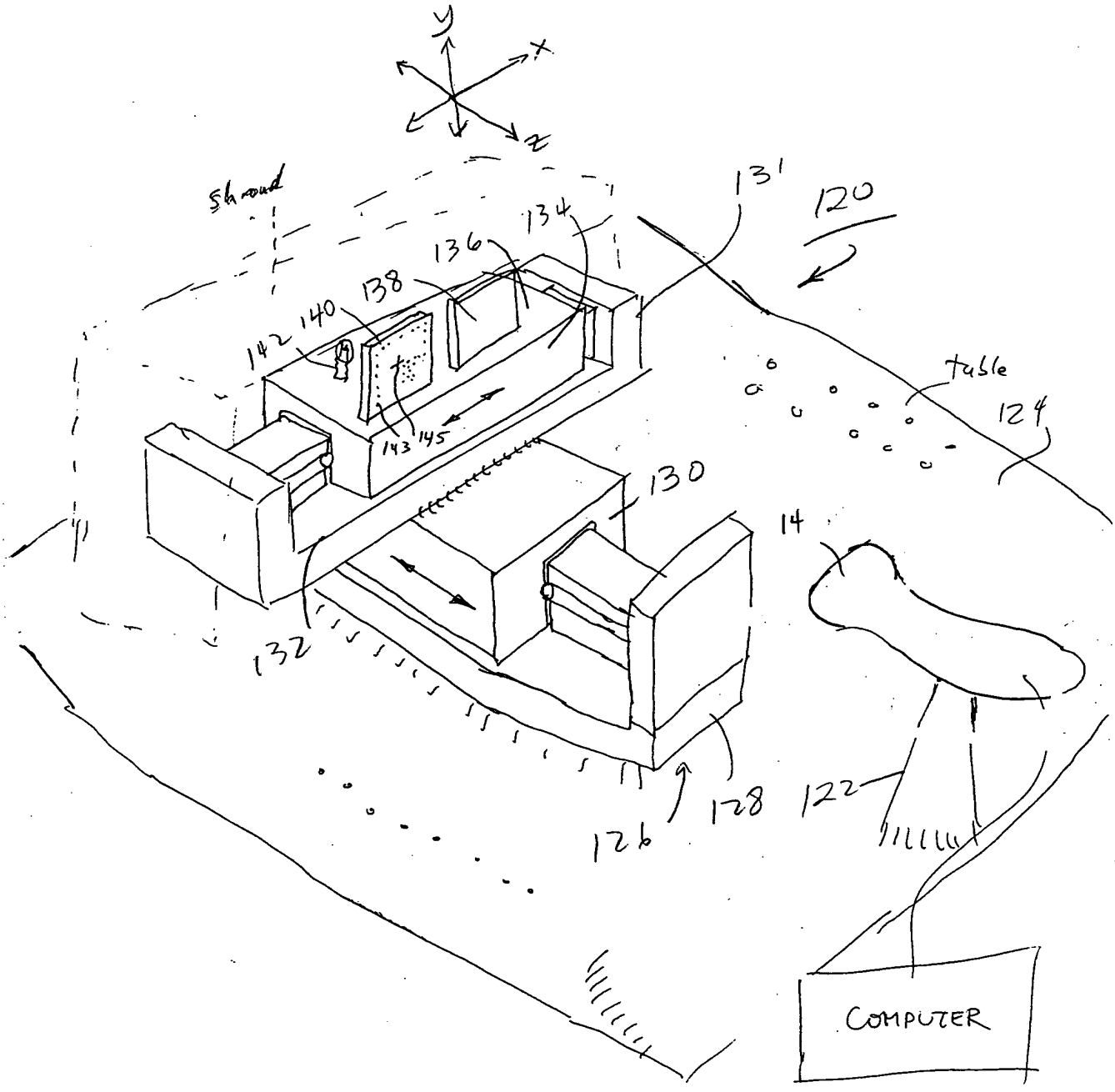

59
58
108
110
56
106
100
projection part lens system
104
102
14
50
48
53A
100
53
51

Fig. 7

Fig. 8


y
x
z
shroud
131
120
134
136
138
140
142
143
145
table
124
130
14
132
126
128
122
COMPUTER

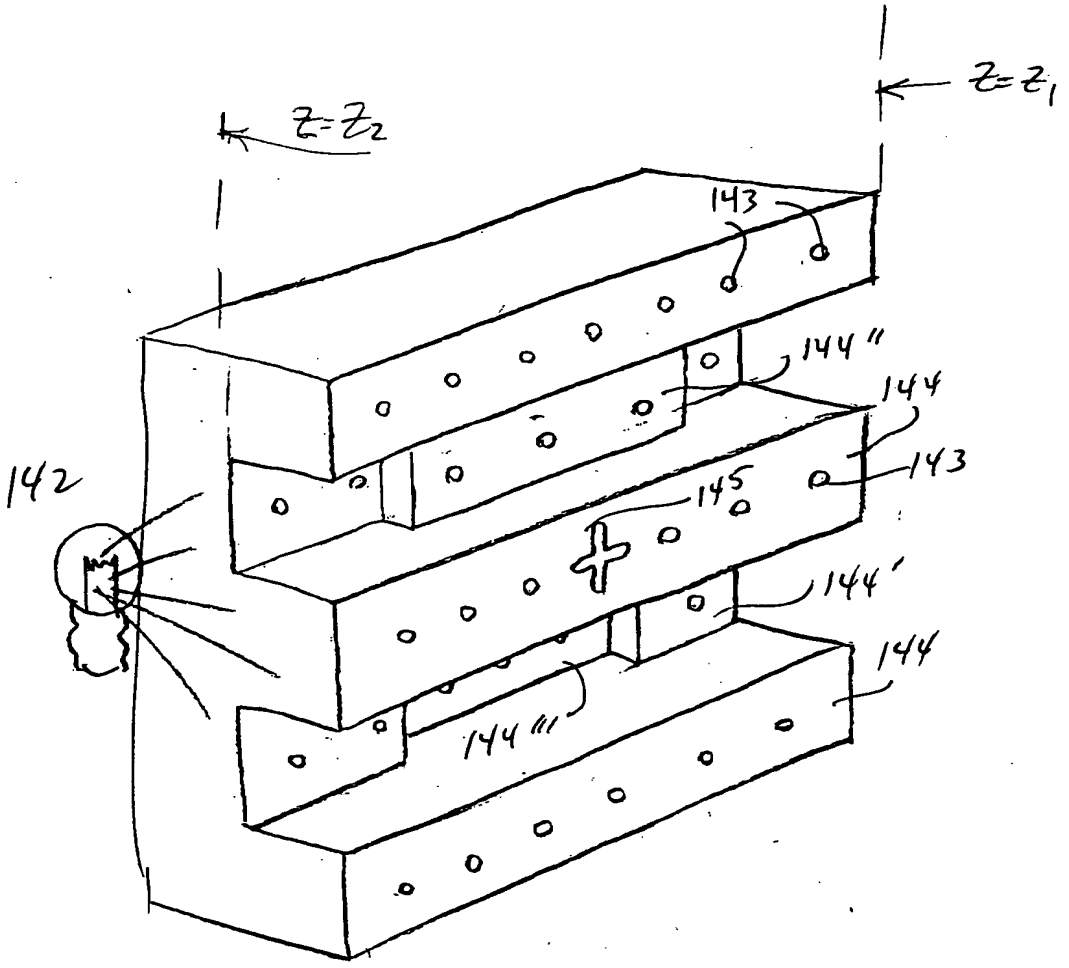


Fig. 8A

Fig. 9

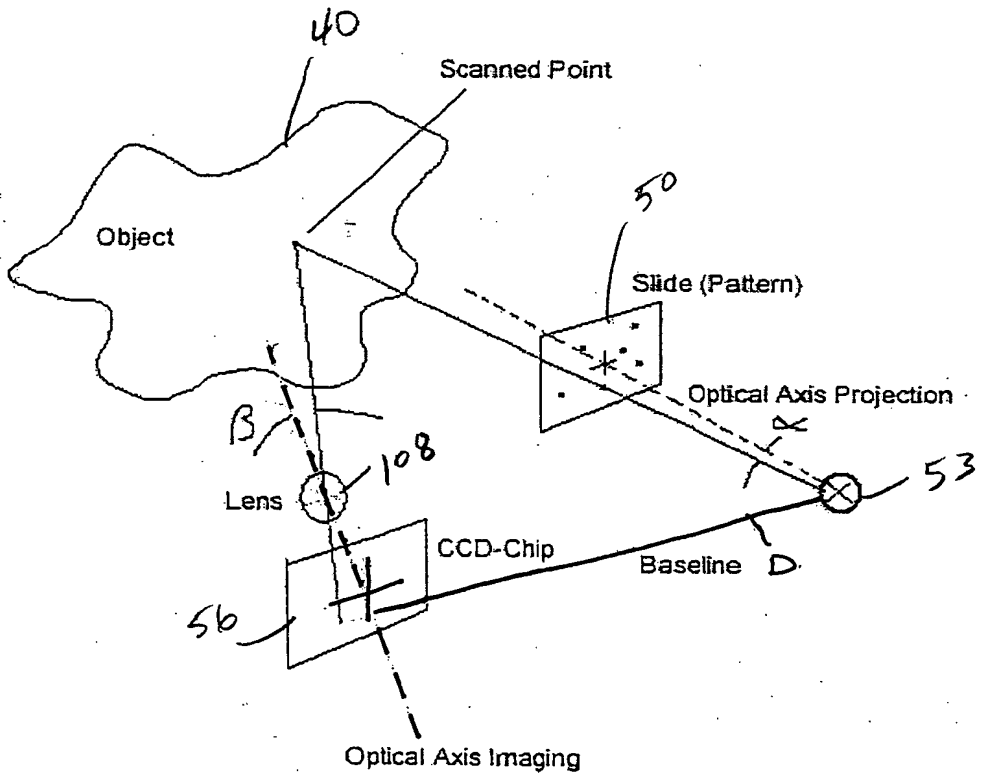

40
Scanned Point
Object
50
Slide (Pattern)
Optical Axis Projection
α
β
108
Lens
53
CCD-Chip
Baseline
D
56
Optical Axis Imaging

Fig. 9B

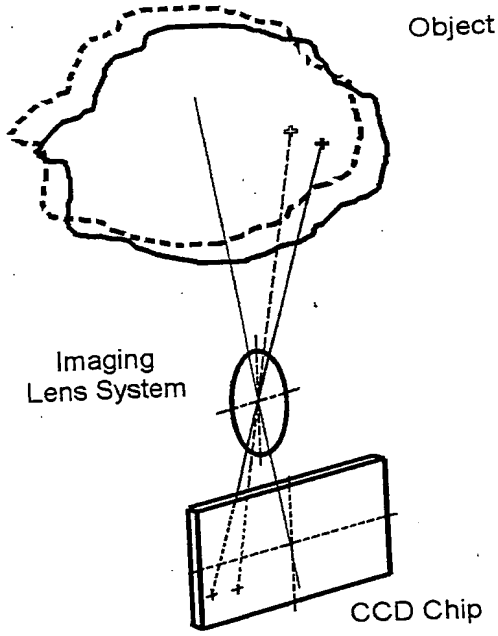
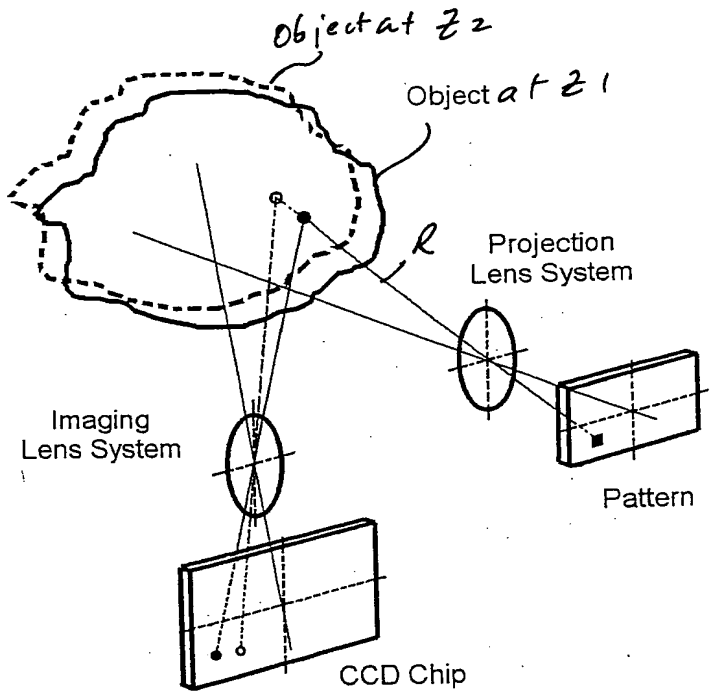
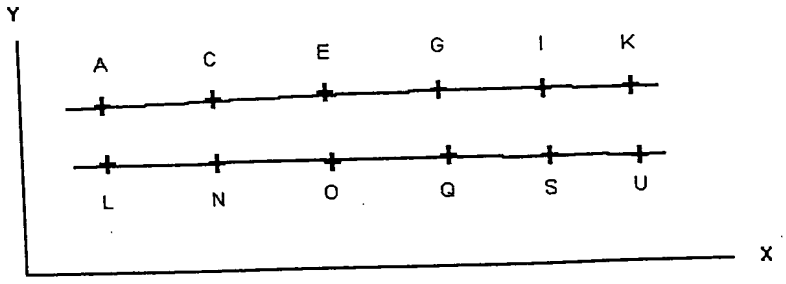


Fig. 9A





Pixel coordinates for portions of the pattern assigned to a certain Z-level

Fig. 9C

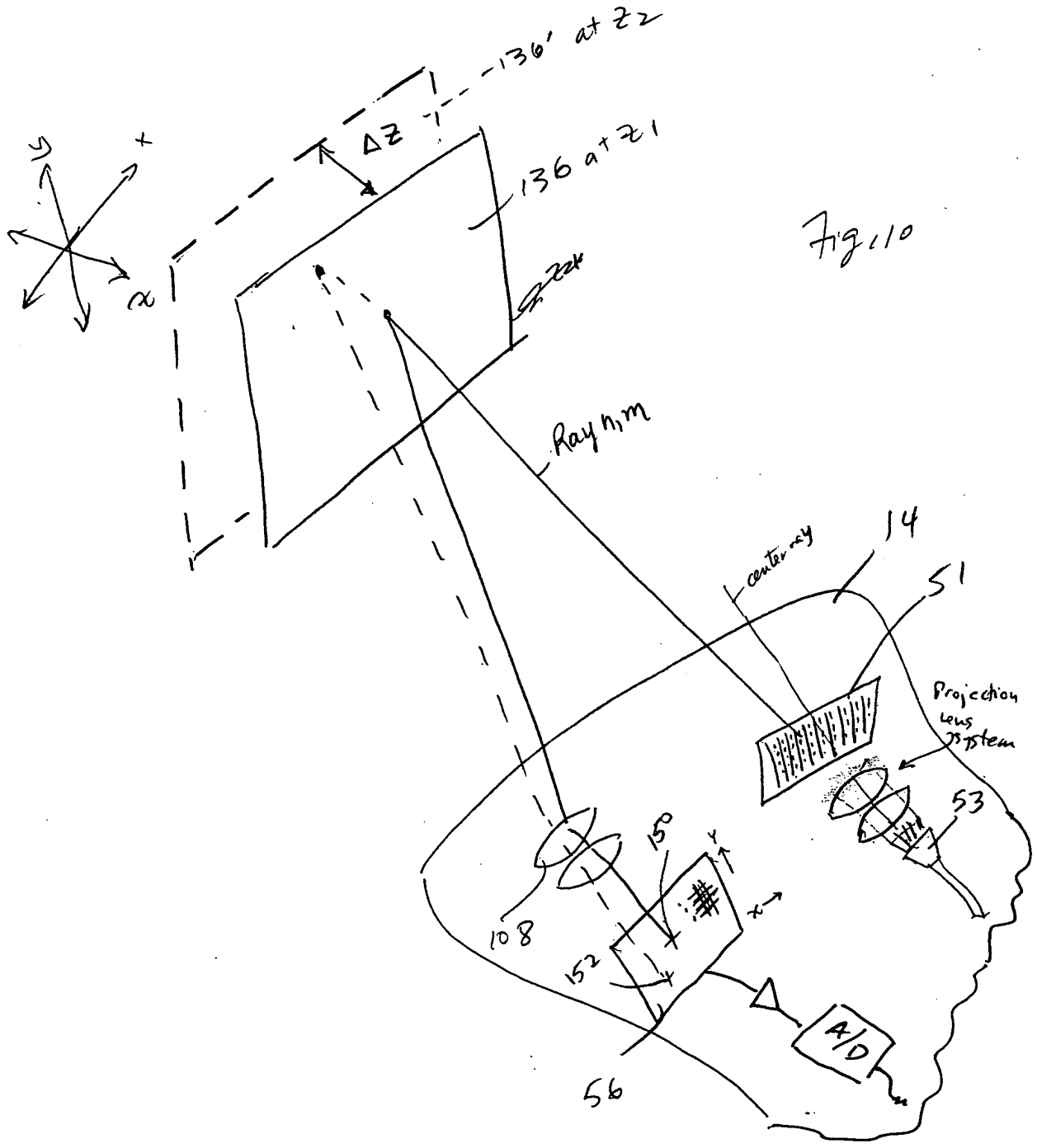

y
x
z
ΔZ
136' at Z2
136 at Z1
Ray n,m
14
center ray
51
Projection lens system
53
15
108
152
A/D
56

Fig. 10

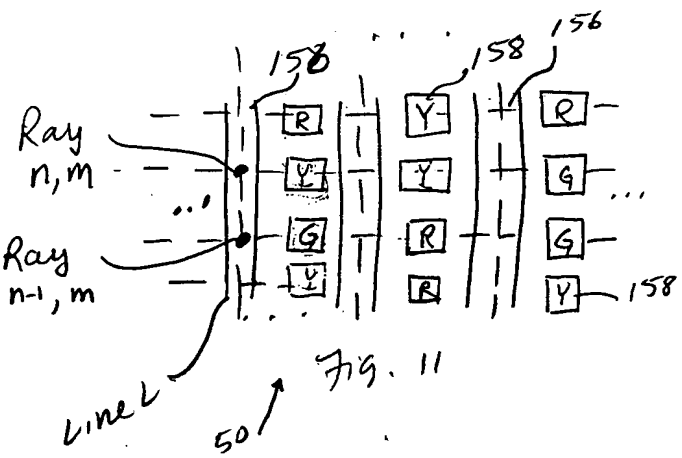


Fig. 11

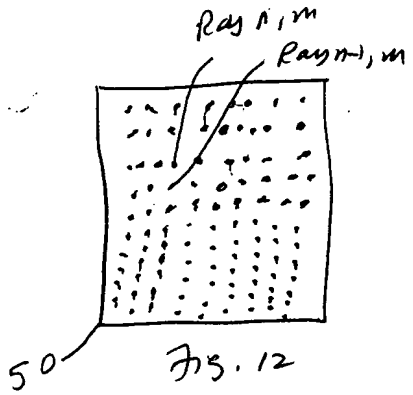


Fig. 12

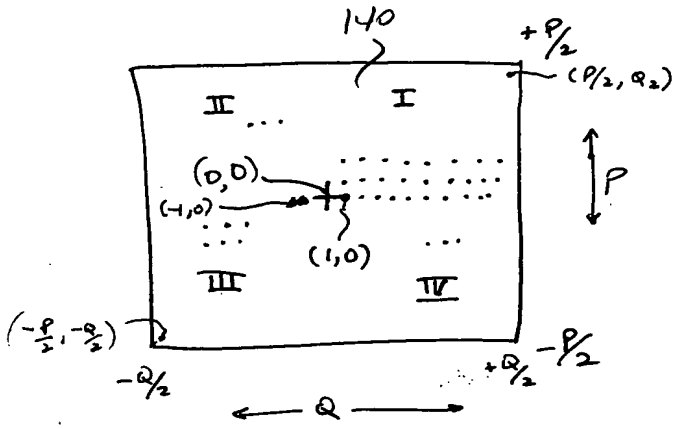


Fig. 13

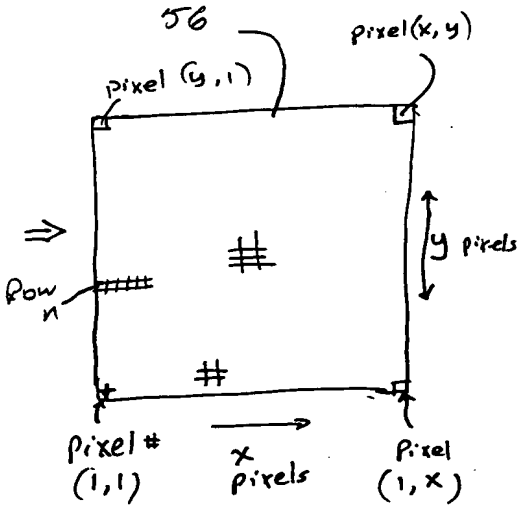


FIG. 14

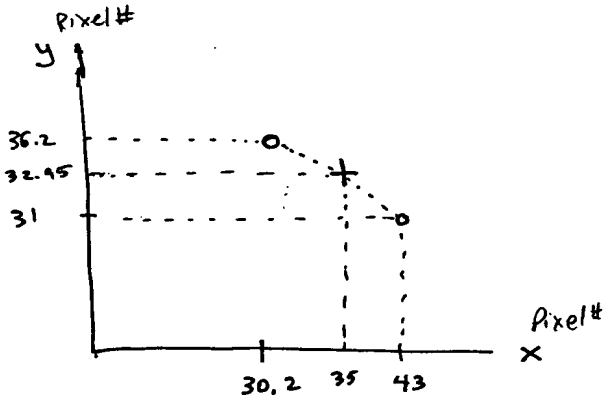


Fig. 15

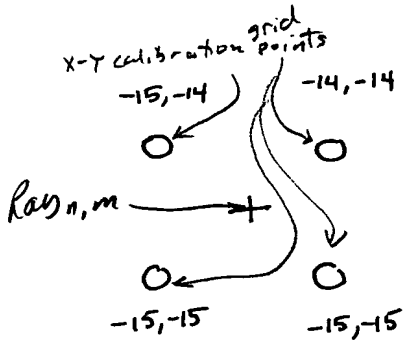
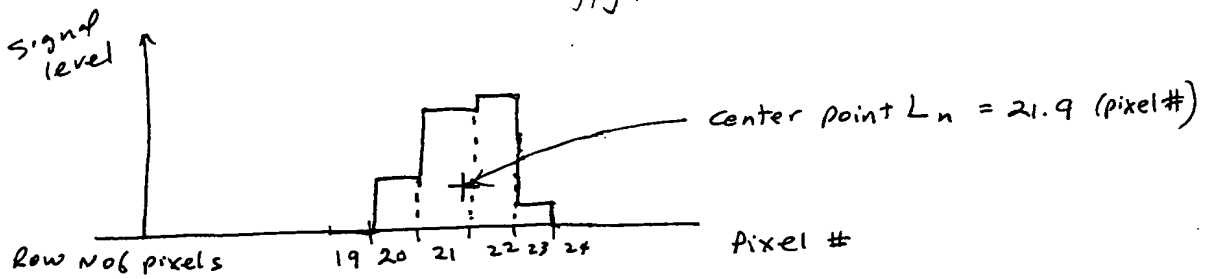


Fig. 16

Fig. 17



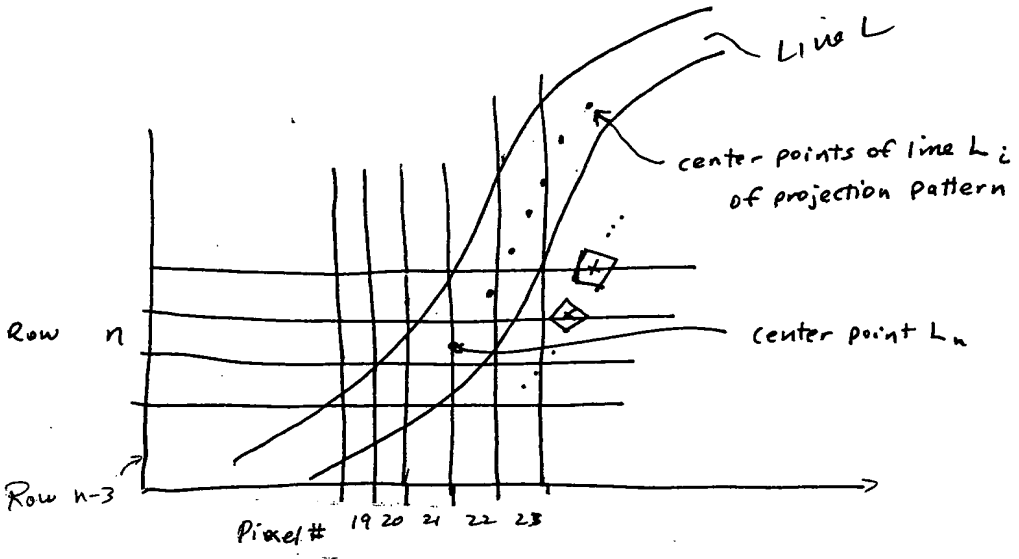


Fig. 18

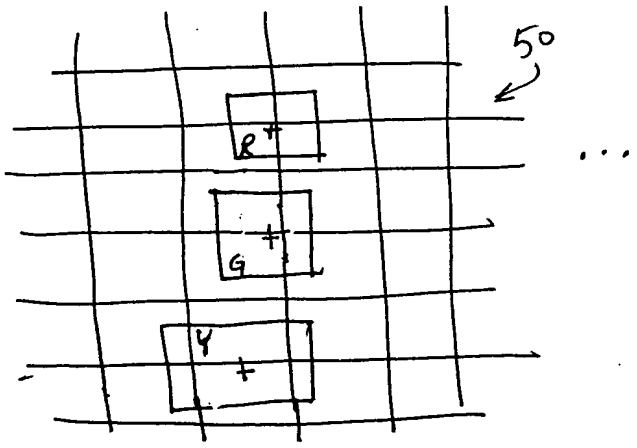


Fig. 19

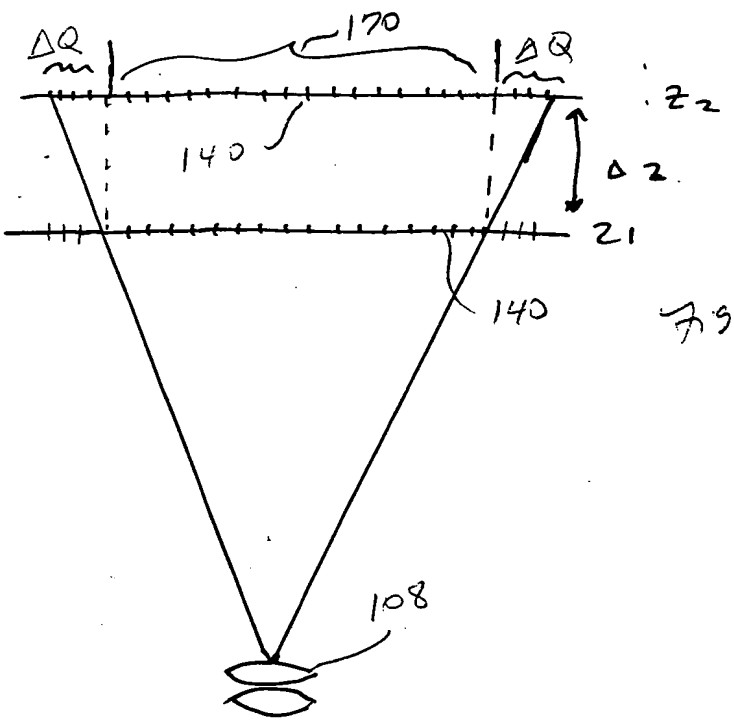

ΔQ
170
ΔQ
Z_2
140
Δ Z
Z1
140
108

Fig. 20

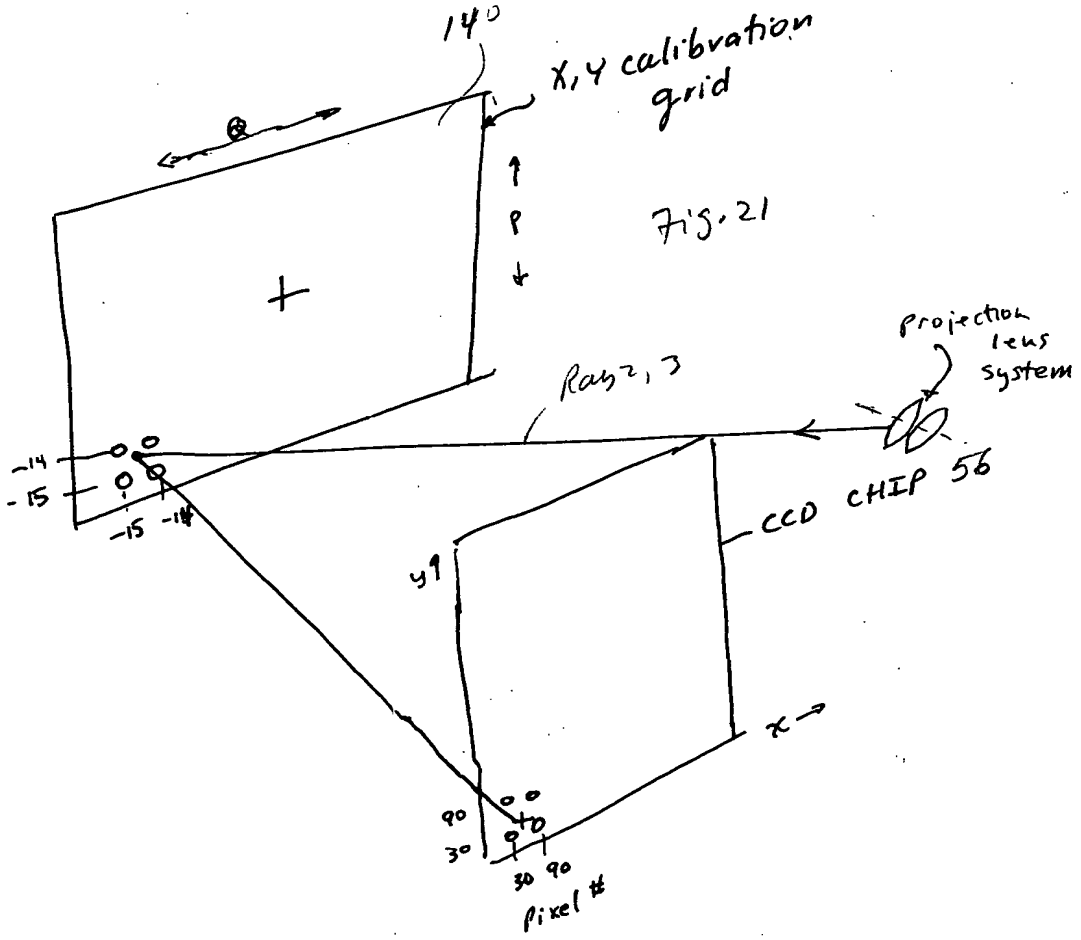

140
X, Y calibration grid
P
Projection lens system
Rays 2, 3
-14
-15
-15
-14
CCD CHIP 56
y
x
90
30
30
90
Pixel #

Fig. 21

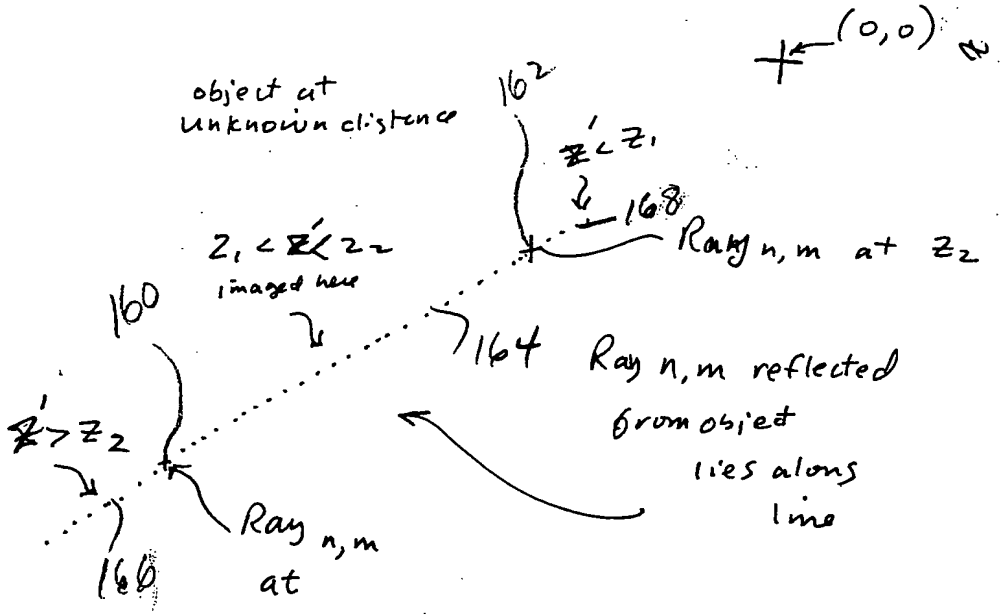
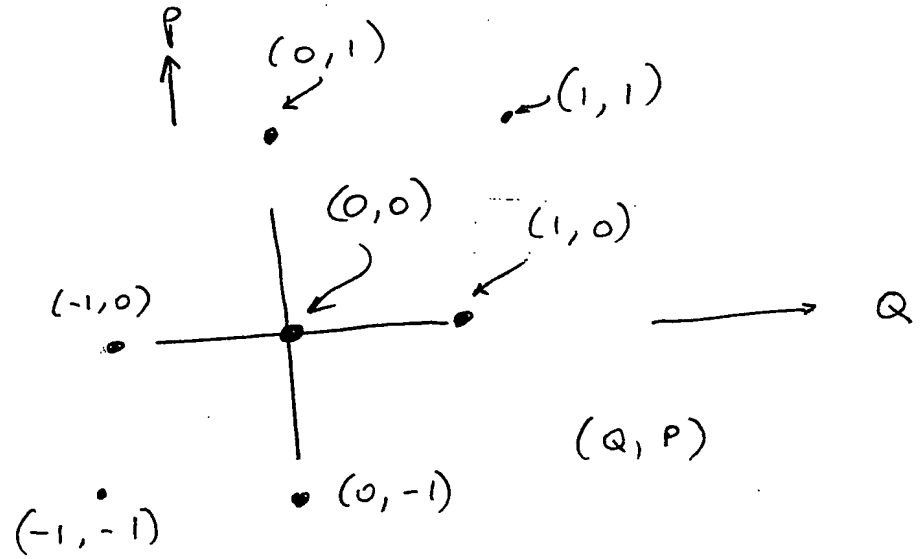

(0,0)
z
object at unknown distance
162
z' < z1
168
Ray n, m at z2
z1 < z' < z2
imaged here
160
164
Ray n, m reflected from object lies along line
z' > z2
Ray n, m at
166

Fig. 22

Fig. 23


P
(0,1)
(1,1)
(0,0)
(1,0)
(-1,0)
Q
(Q, P)
(0,-1)
(-1,-1)

CCDx, CCDy = Pixel #, in subpixel resolution

Fig. 24

(before)

Calibration Table #1

		Line 1						Line 2						...	Line N				
		Row 1	Row 2	Row 3	Row 4	...	Row M	Row 1	Row 2	Row 3	Row 4	...	Row M		Row 1	Row 2	....	Row M
Z_1	CCD X	1.0	1.1	1.5	2.1		...	27.1	29.5	30.2	37.1							
	mm Distance																	
	CCD Y	10.2	20.4	32.8	44.5			11.5	21.6	36.2	44							
	mm Distance																	
Z_2	CCD X	3.9	4.5	6.8	12.2			34.0	41.1	43.0	46							
	mm Dist.																	
	CCD Y	12.1	21.5	30.4	46.3			13.2	21.8	31.0	48.2							
	mm Dist.																	

(Q, P)

Calibration Table #2

Quadrant I

		(0,0)	(1,0)	(2,0)	(3,0)	...	(Q/2 − ΔQ, 0)	...	(Q/2, 0)	(0,1)	(1,1)	(2,1)	...	...	(0, P/2)	(1, P/2)	...	(Q/2, P/2)
		Row 0								Row 1					Row + P/2			
Z_1	CCD_X	640.1	700.2	760.6	820.5	..	...		—	640.1	700.2	...			...	...		1,279.5
	CCD_Y	640.1	640.1	640.3	640.4		...		—	701.2	701.5	...			...	...		1279.4
Z_2	CCDX	640.2	680.3	741.2	801.6		...		1,279.5	...	681.2	...			...	...		1256.4
	CCD_Y	640.2	640.3	640.1	640.1		...		640.2	...	680.9	...			...	...		1251.5

Quadrant II

		(−1,0)	(−2,0)	(−3,0)	(−4,0	...	(−Q/2 − ΔQ, 0)	...	(−Q/2, 0)	(−1,1)	(−2,1)	(−3,1)	...	...	(−1, P/2)	(−2, P/2)	...	(−Q/2, P/2)
		Row								Row 1					Row + P/2			
	CCD_X																	
Z_1	CCDY																	
	CCD_X																	
Z_2	CCDY																	

Quadrant III

		(−1,−1)	(−2,−1)	...
Z_1	CCD_X			
	CCDY			
Z_2	CCDX			
	CCDY			

Quadrant IV

		(0,−1)	(1,−1)	...
Z_1	CCDX			
	CCDY			
Z_2	CCDX			
	CCDY			

Fig. 25

CCD_x, CCD_y = Pixel #, insubpixel resolution

Fig. 26

Calibration Table #1 (after)

		Pattern Line 1				...		Pattern Line 2				...		...	Line N			
		Row 1	Row 2	Row 3	Row 4	...	Row M	Row 1	Row 2	Row 3	Row 4	...	Row M		Row 1	Row 2	...	Row M
	CCD_x	1.0	1.1	1.5	2.1		...	27.1	29.5	30.2	37.1							
Z_1	mm Distance									-14.6								
	CCD_y	10.2	20.4	32.8	44.5			11.5	21.6	36.2	44							
	mm Distance									-14.4								
	CCD_x	3.9	4.5	6.8	12.2			34.0	41.1	43.0	46							
Z_2	mm Dist.									-14.8								
	CCD_y	12.1	21.5	30.4	46.3			13.2	21.8	31.0	48.2							
	mm Dist.									-15.8								

after

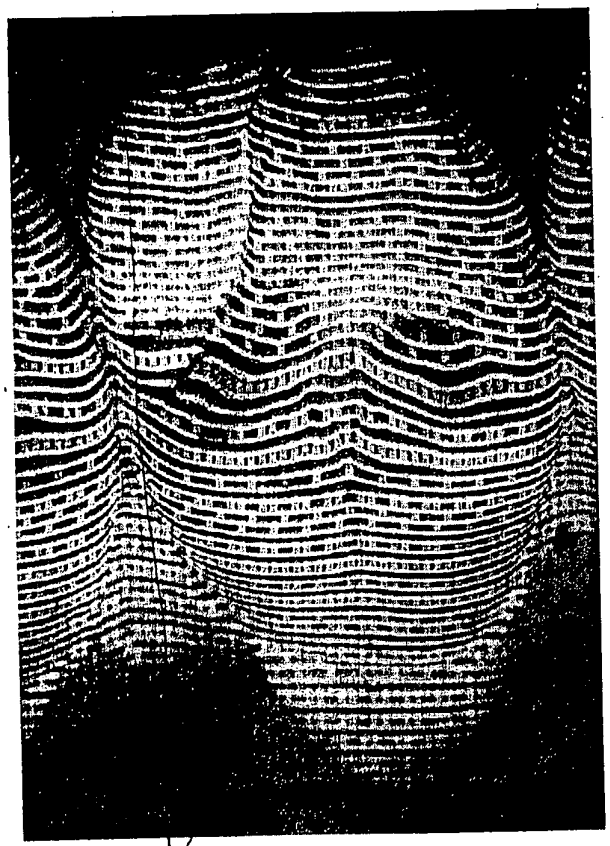


Fig. 27

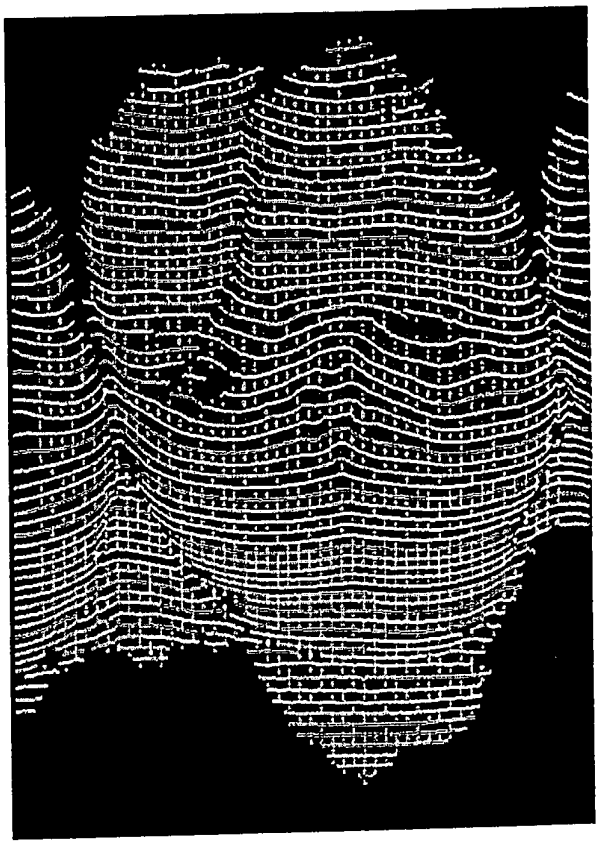


Fig. 28

FIG. 29

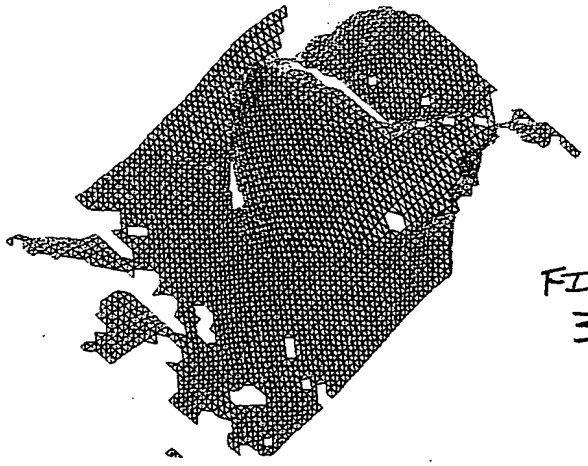


FIG. 30

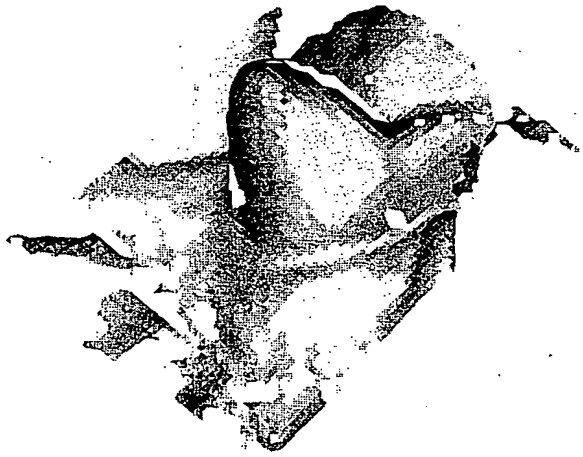


FIG. 31

FIG. 32

FIG. 33

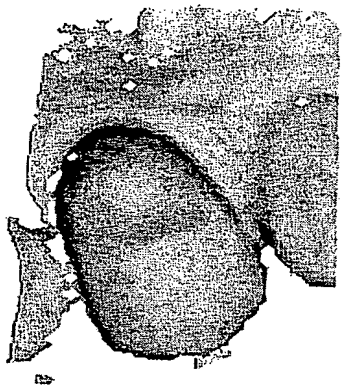
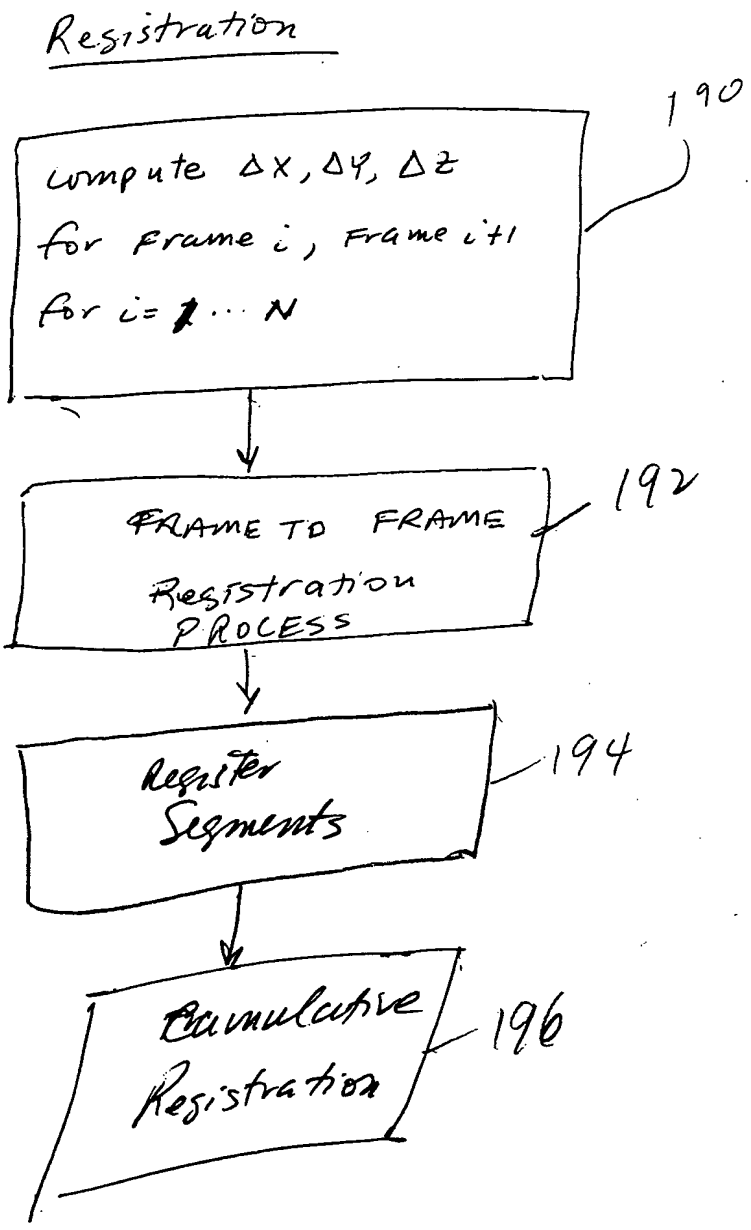


FIG. 34

FIG. 35

Fig. 36


Registration
compute ΔX, ΔY, ΔZ
for Frame i, Frame i+1
for i = 1 ... N
190
FRAME TO FRAME
Registration
PROCESS
192
Register
Segments
194
Cumulative
Registration
196

19a

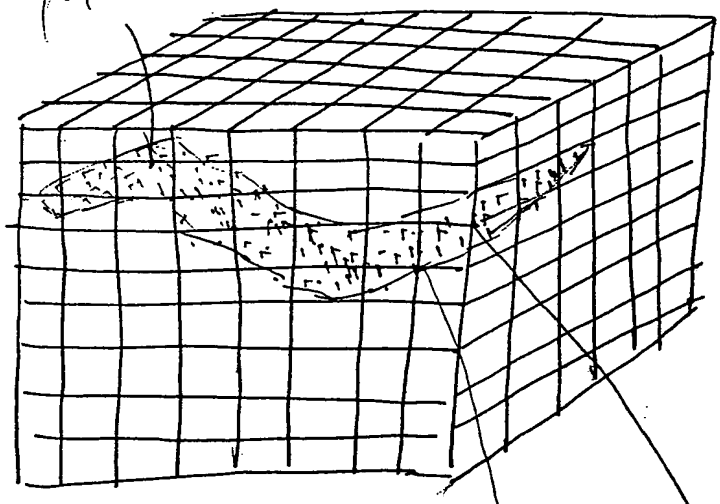


Fig. 37A

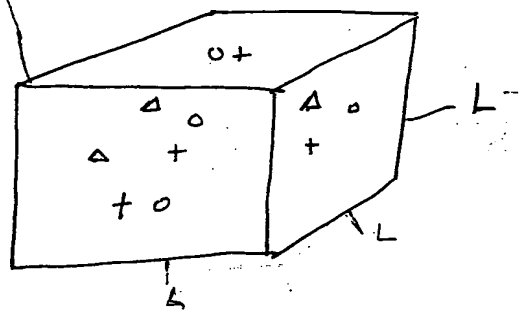


Fig. 37B

L = 1.0 mm

Δ = points of frame i

+ = points of frame i+1

o = points of frame i+2

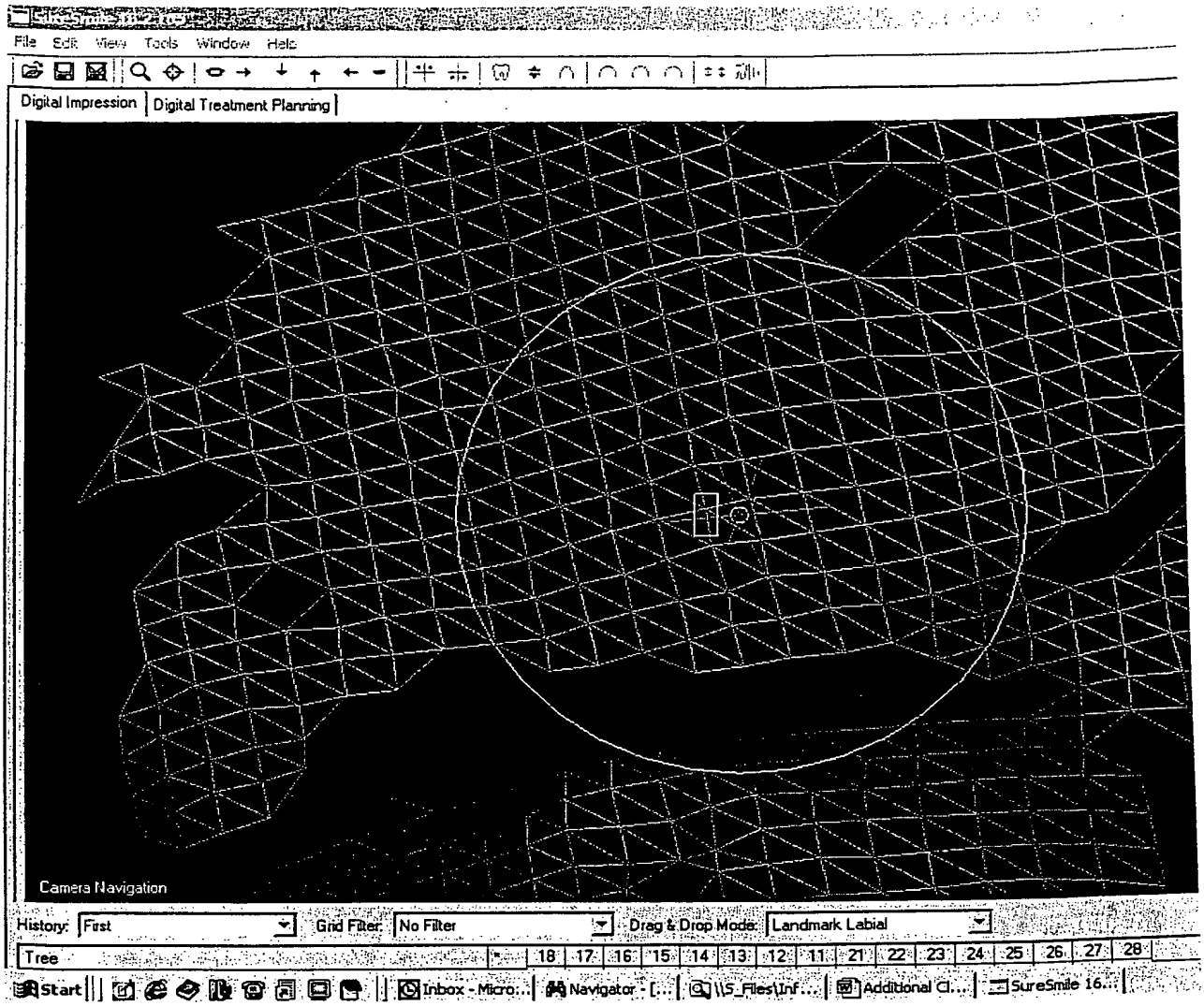

File Edit View Tools Window Help
Digital Impression
Digital Treatment Planning
Camera Navigation
History: First
Grid Filter: No Filter
Drag & Drop Mode: Landmark Labial
Tree
18 17 16 15 14 13 12 11 21 22 23 24 25 26 27 28
Start
Inbox - Micro...
Navigator - [...
\\S_Files\Inf...
Additional Cl...
SureSmile 16...

Figure 37c

f

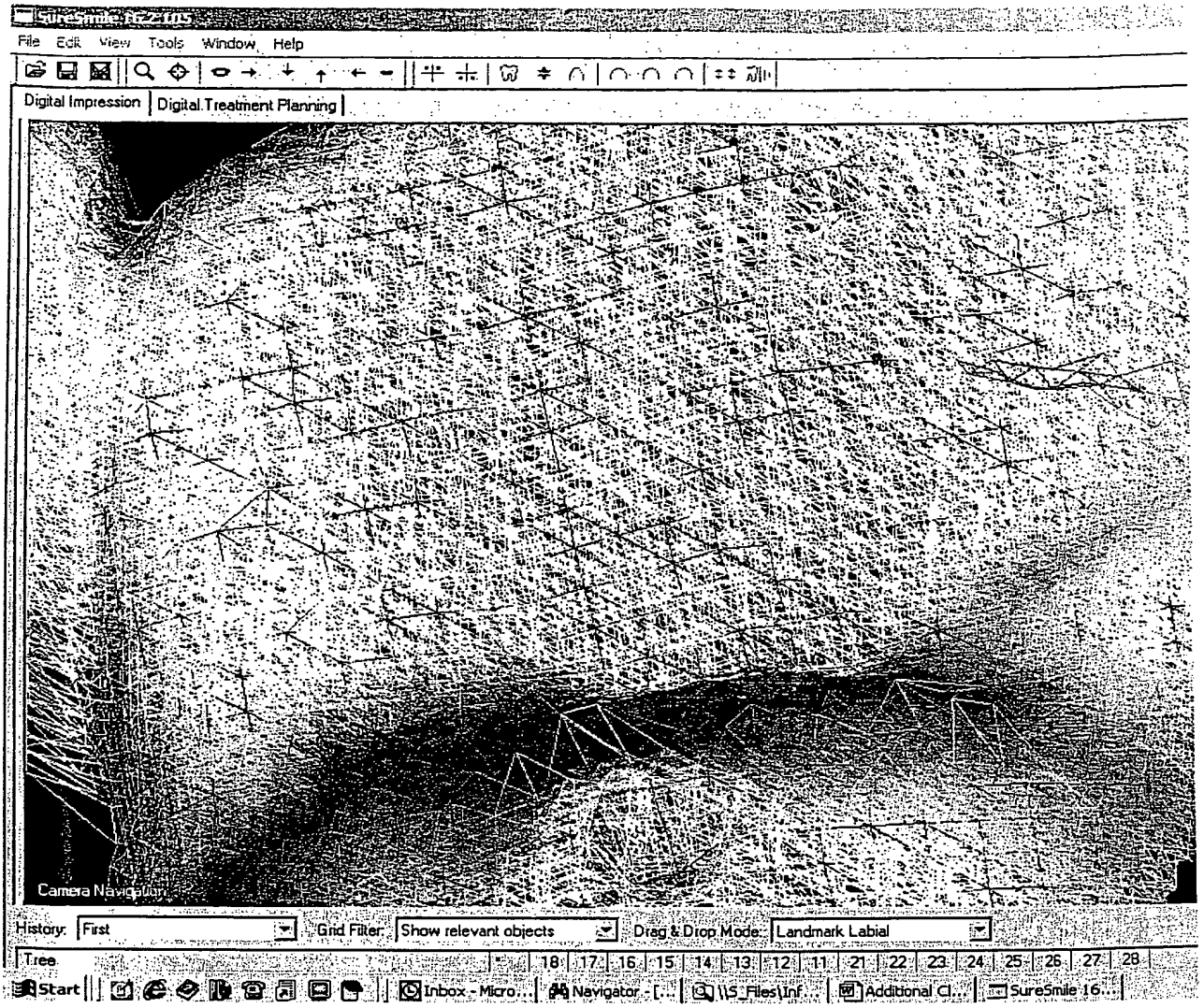
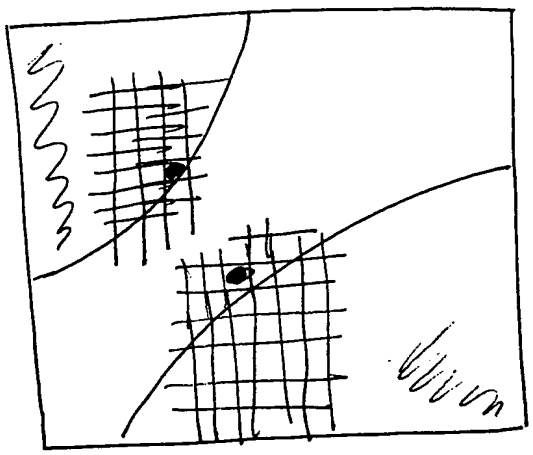
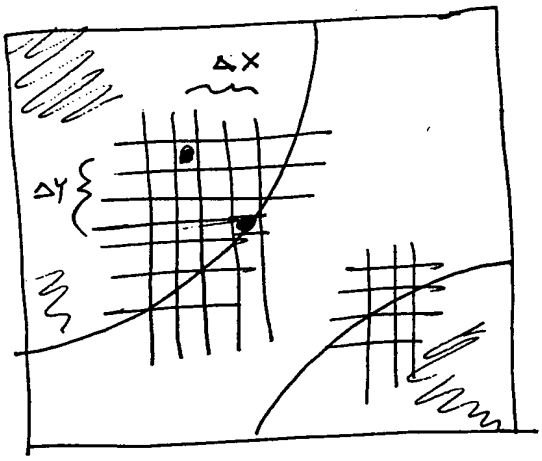

File Edit View Tools Window Help
Digital Impression
Digital Treatment Planning
Camera Navigation
History: First
Grid Filter: Show relevant objects
Drag & Drop Mode: Landmark Labial
Tree
18 17 16 15 14 13 12 11 21 22 23 24 25 26 27 28
Start
Inbox - Micro...
Navigator - [...
\\S_Files\Inf...
Additional Cl...
SureSmile 16...

Fig-32D



Frame i

Fig. 38A



Frame i+1

Fig. 38B

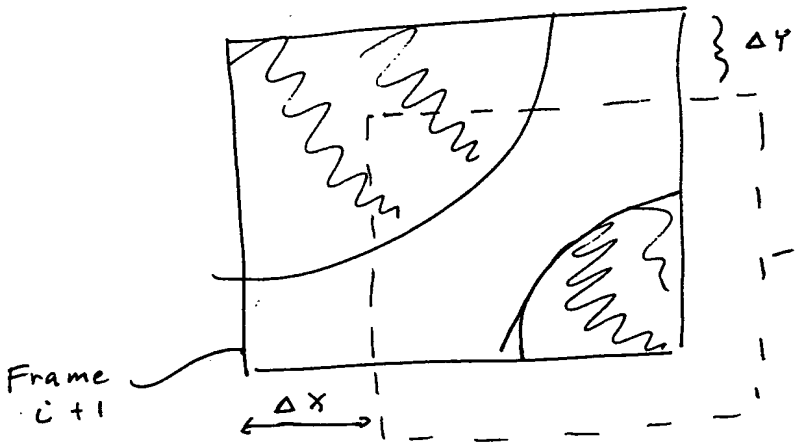
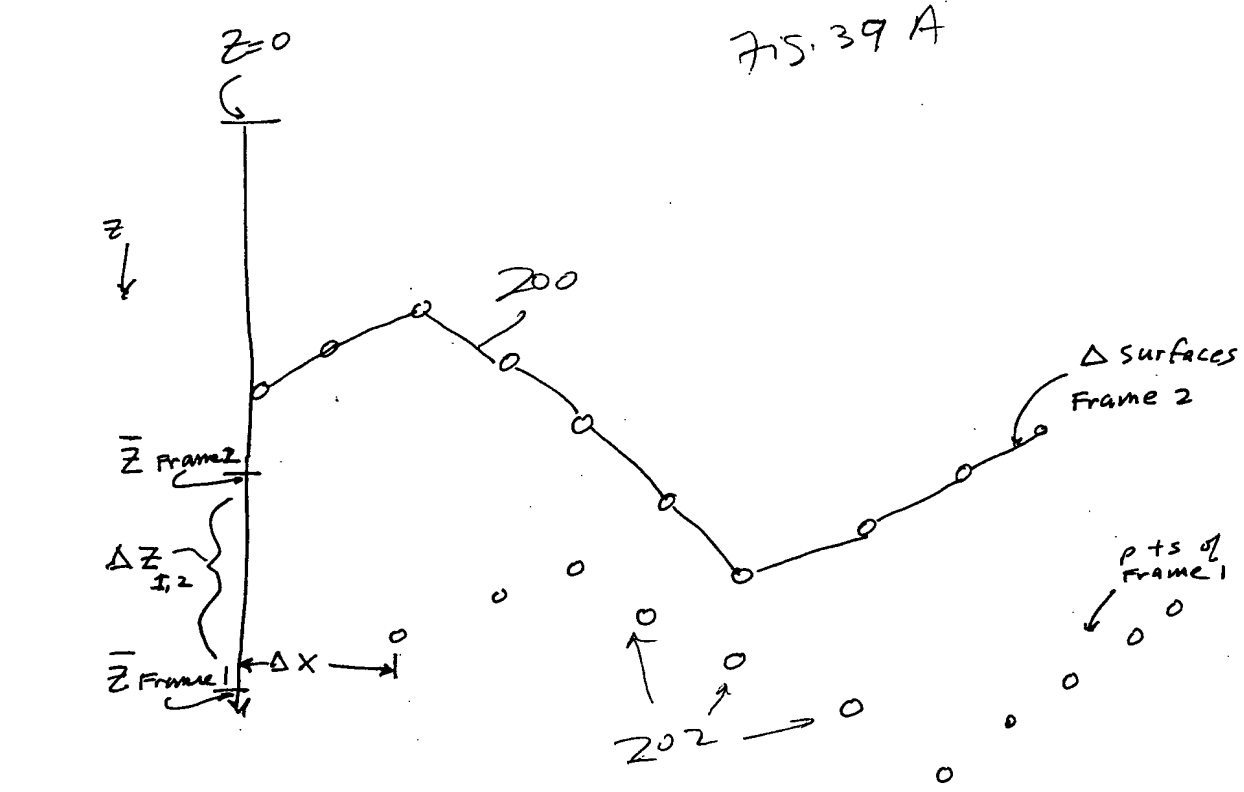
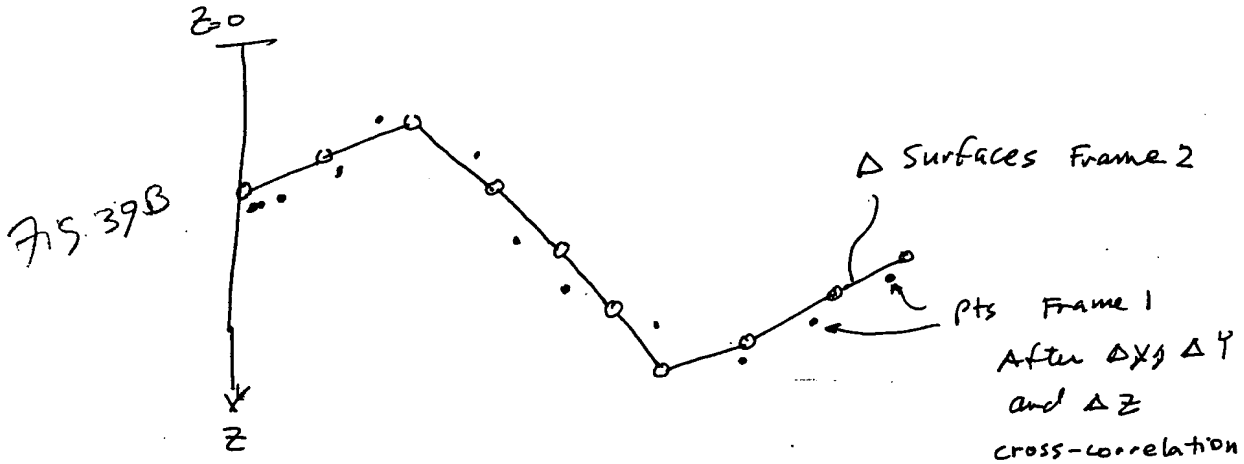


Fig. 38C


Z=0
Z
200
Δ surfaces
Frame 2
$\bar{Z}$ Frame2
$\Delta Z_{1,2}$
pts of
Frame 1
$\bar{Z}$ Frame 1
ΔX
202

75.39A


Z=0
Δ Surfaces Frame 2
pts Frame 1
After ΔX, ΔY
and ΔZ
cross-correlation
Z

75.39B

Fig. 40A

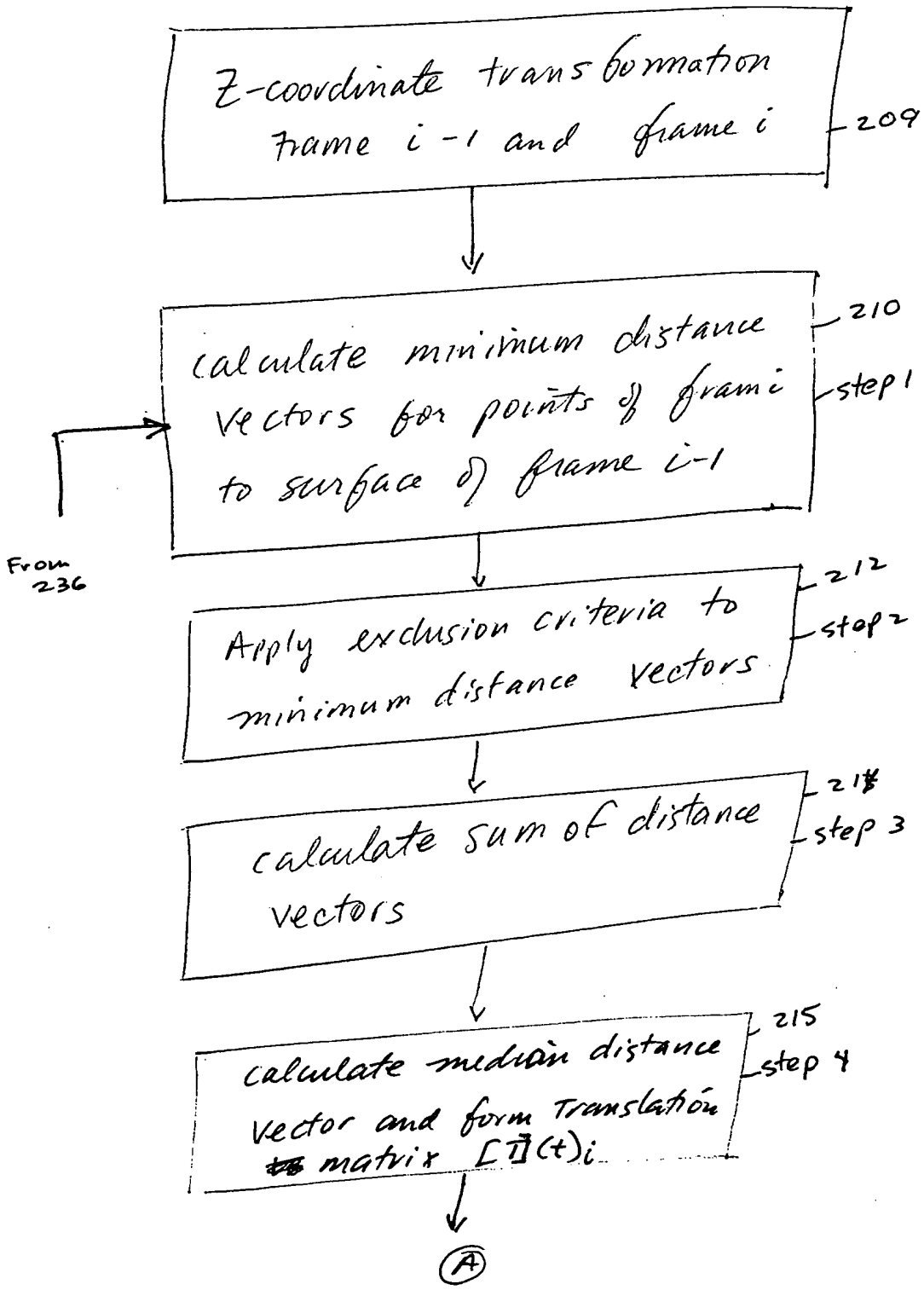
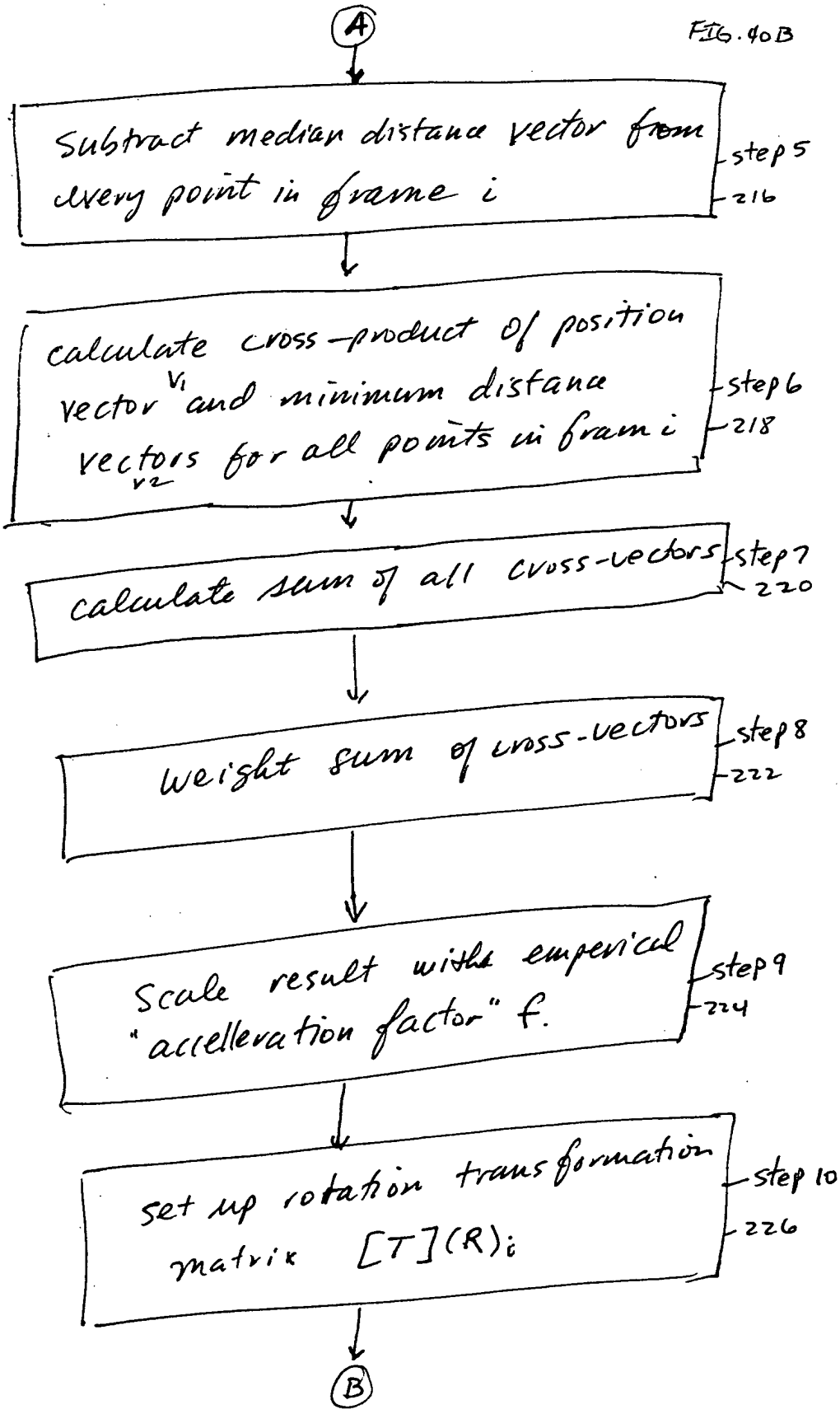
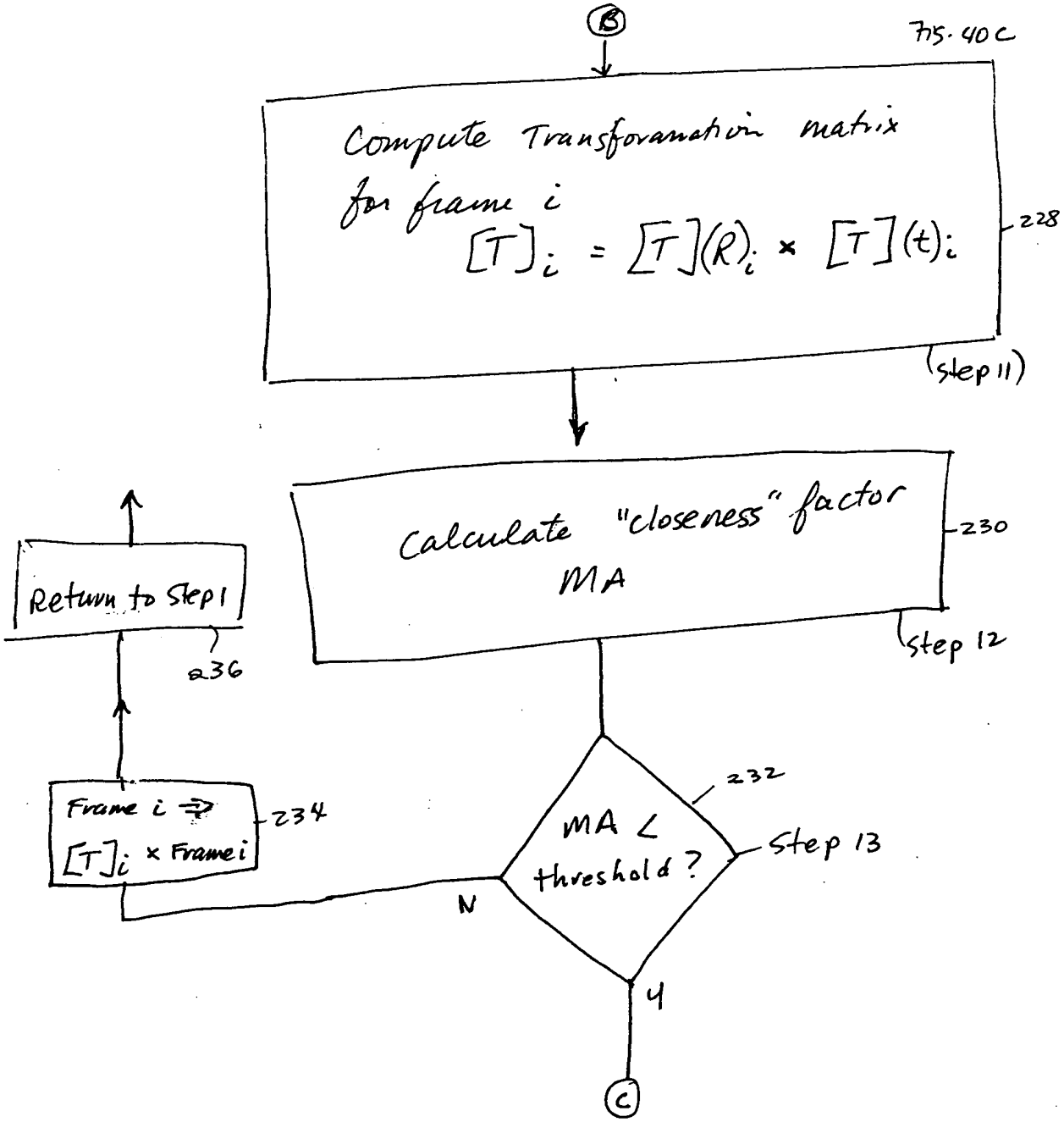

Z-coordinate transformation frame i-1 and frame i
209
calculate minimum distance vectors for points of frame i to surface of frame i-1
210
step 1
From 236
Apply exclusion criteria to minimum distance vectors
212
step 2
calculate sum of distance vectors
21#
step 3
calculate median distance vector and form Translation matrix [T](t)i
215
step 4
A

FIG. 4B


A
Subtract median distance vector from every point in frame i
step 5
216
calculate cross-product of position vector V_1 and minimum distance vectors V_2 for all points in frame i
step 6
218
calculate sum of all cross-vectors
step 7
220
weight sum of cross-vectors
step 8
222
Scale result with empirical "acceleration factor" f.
step 9
224
set up rotation transformation matrix [T](R)i
step 10
226
B


B
Fig. 40C
Compute Transformation matrix for frame i
$[T]_i = [T](R)_i \times [T](t)_i$
228
(step 11)
Calculate "closeness" factor MA
230
(step 12)
Return to Step 1
236
Frame i ⇒ $[T]_i$ x Frame i
234
MA < threshold ?
232
step 13
N
Y
C

Frame to Frame registration

Fig. 40D

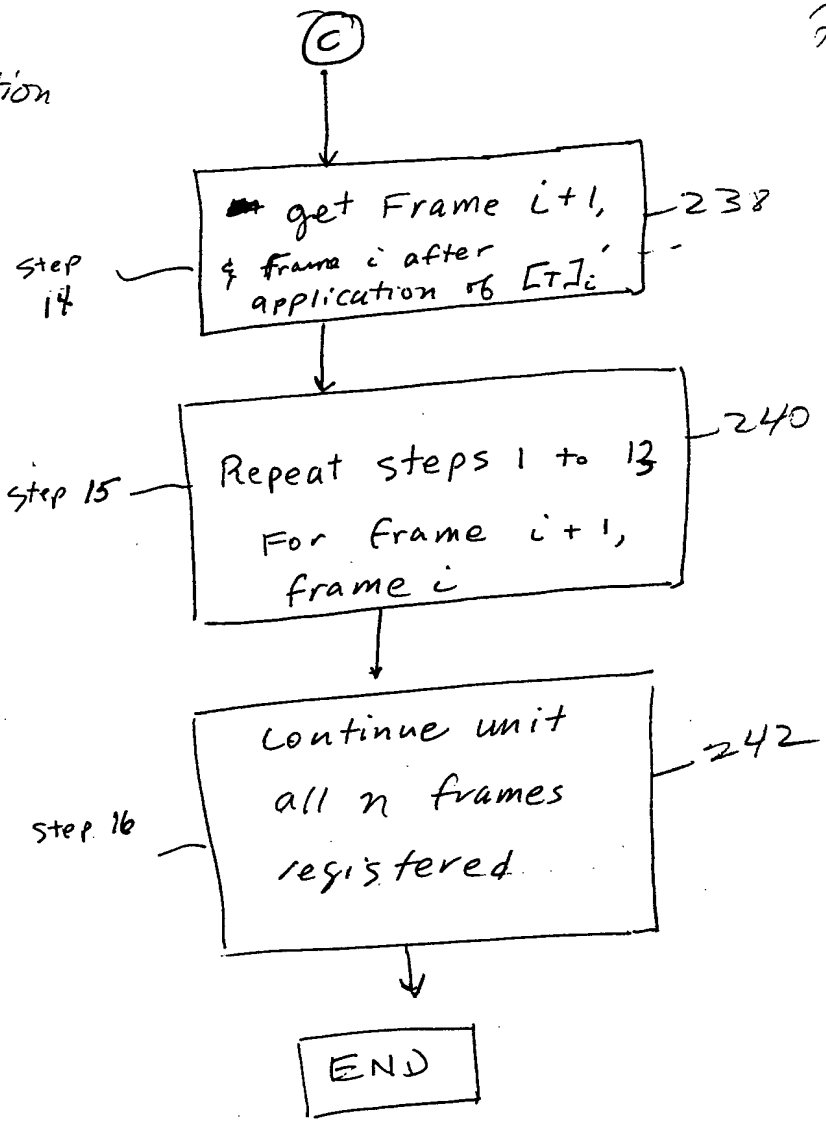


Fig. 41

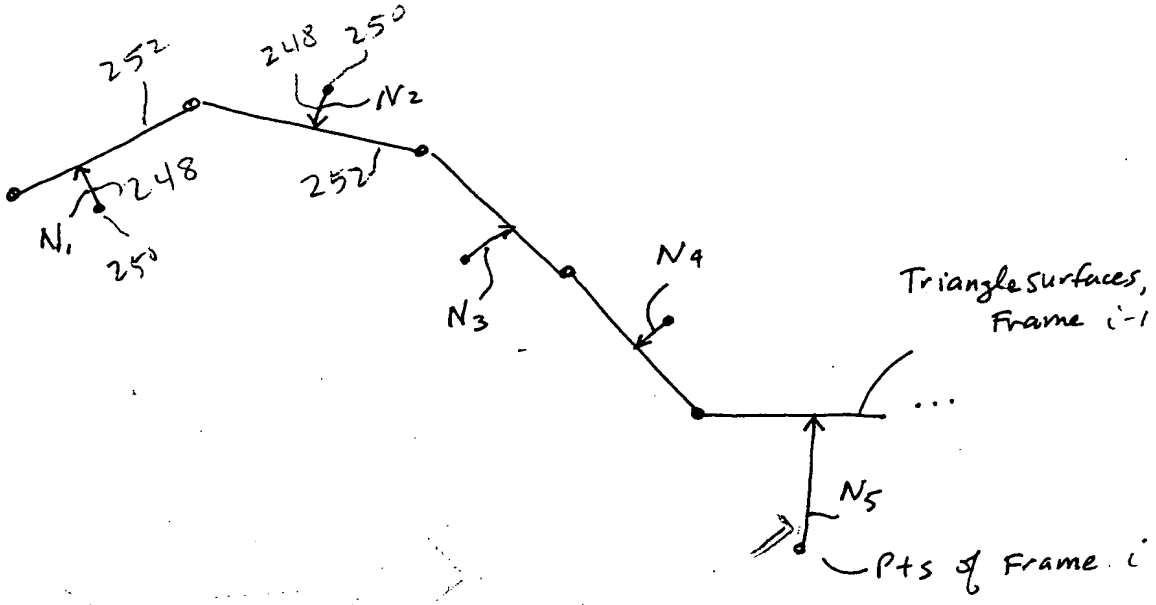


Fig. 42

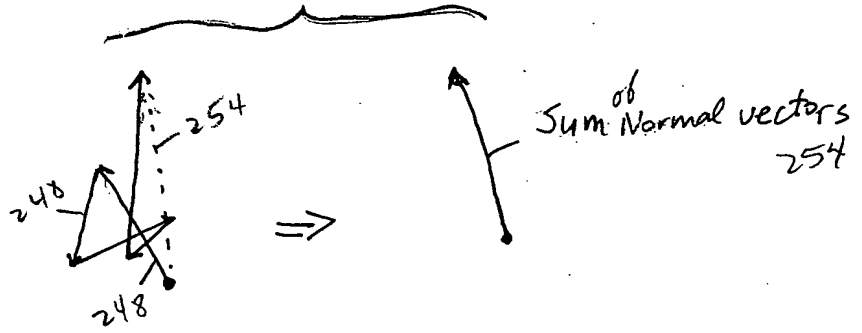


FIG. 43

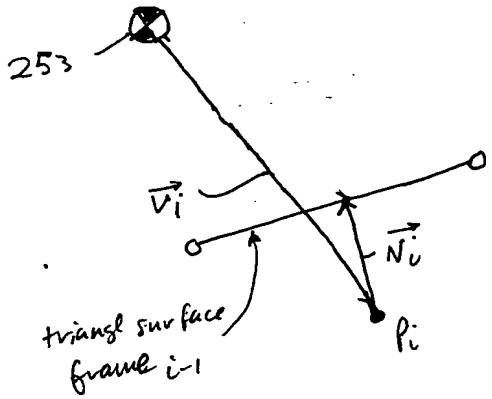
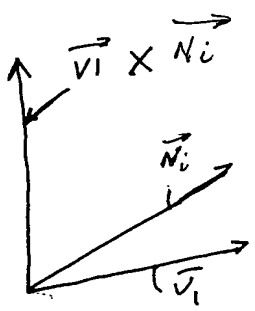


Fig. 44



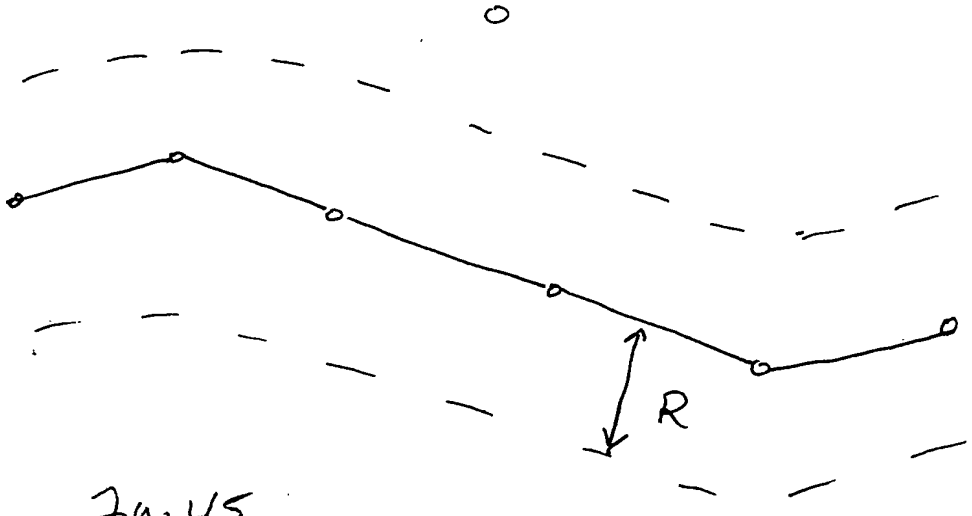

R

Fig. 45

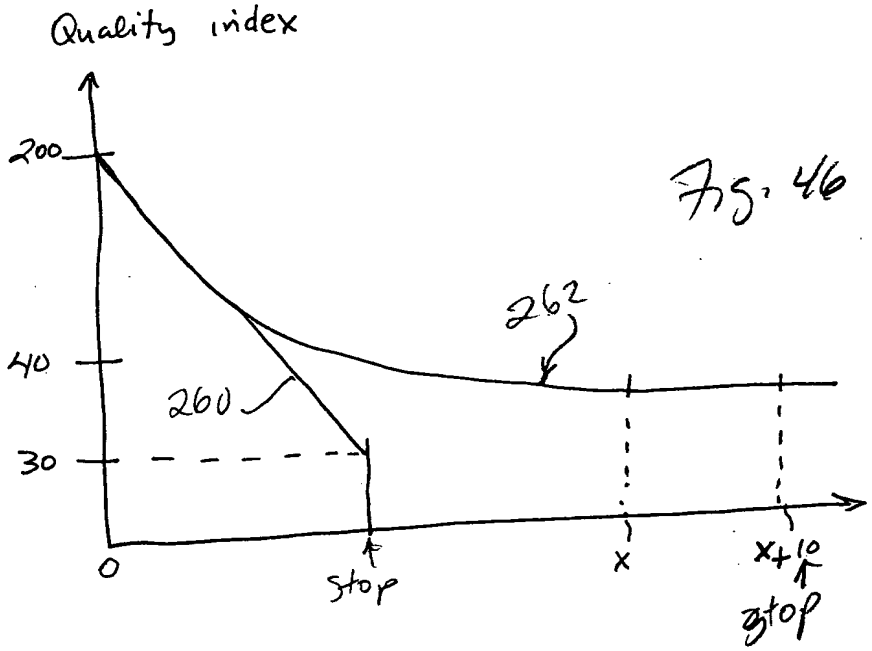

Quality index
200
40
30
260
262
0
stop
x
x+10
stop
Registration iteration

Fig. 46

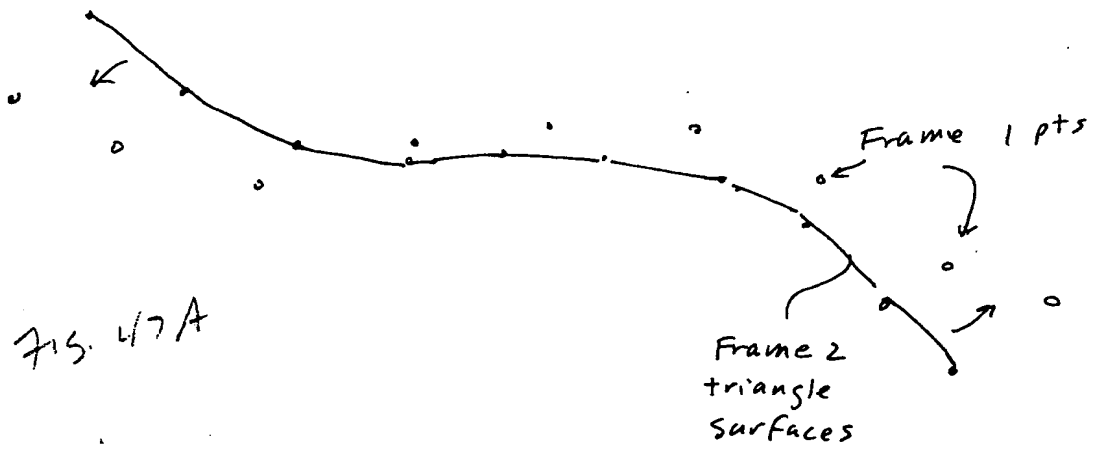


Fig. 47A

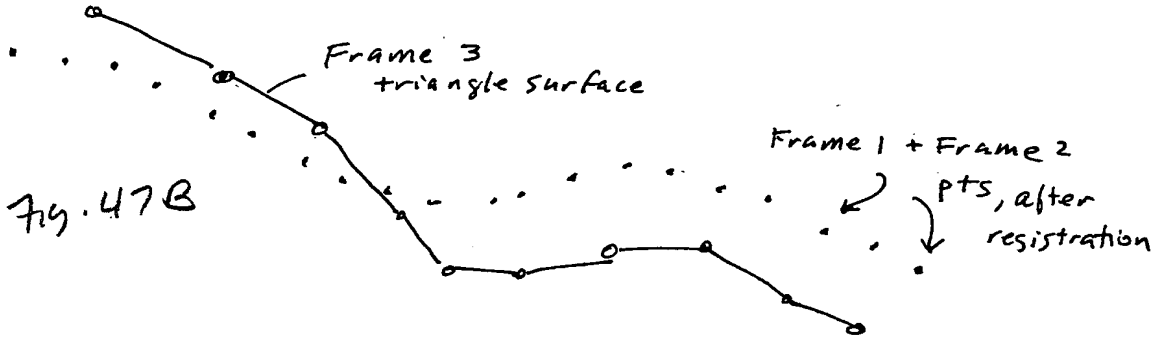


Fig. 47B

Cumulative Registration

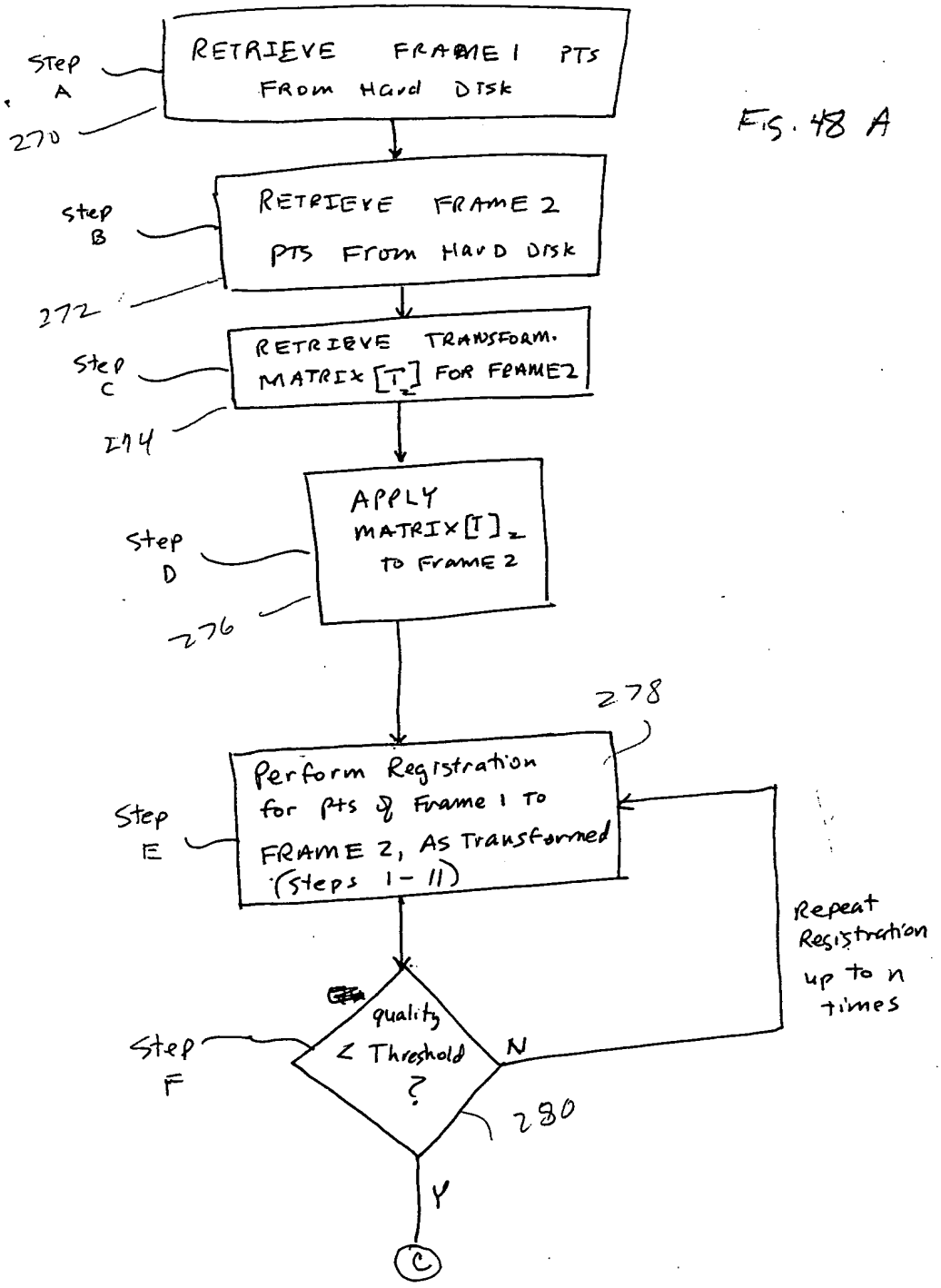


FIG. 48A

Cumulative registration

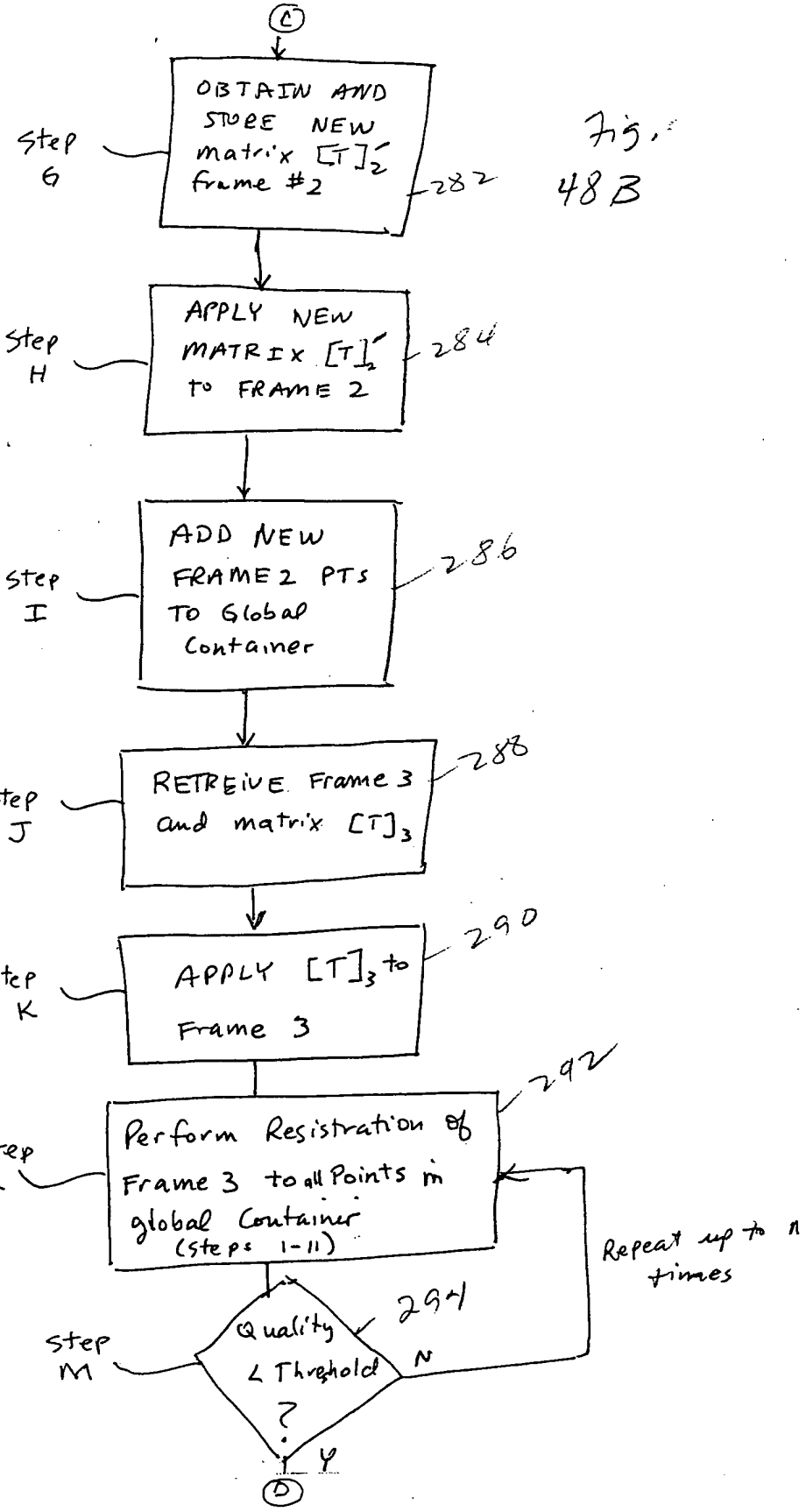


Fig. 48B

Cumulative registration

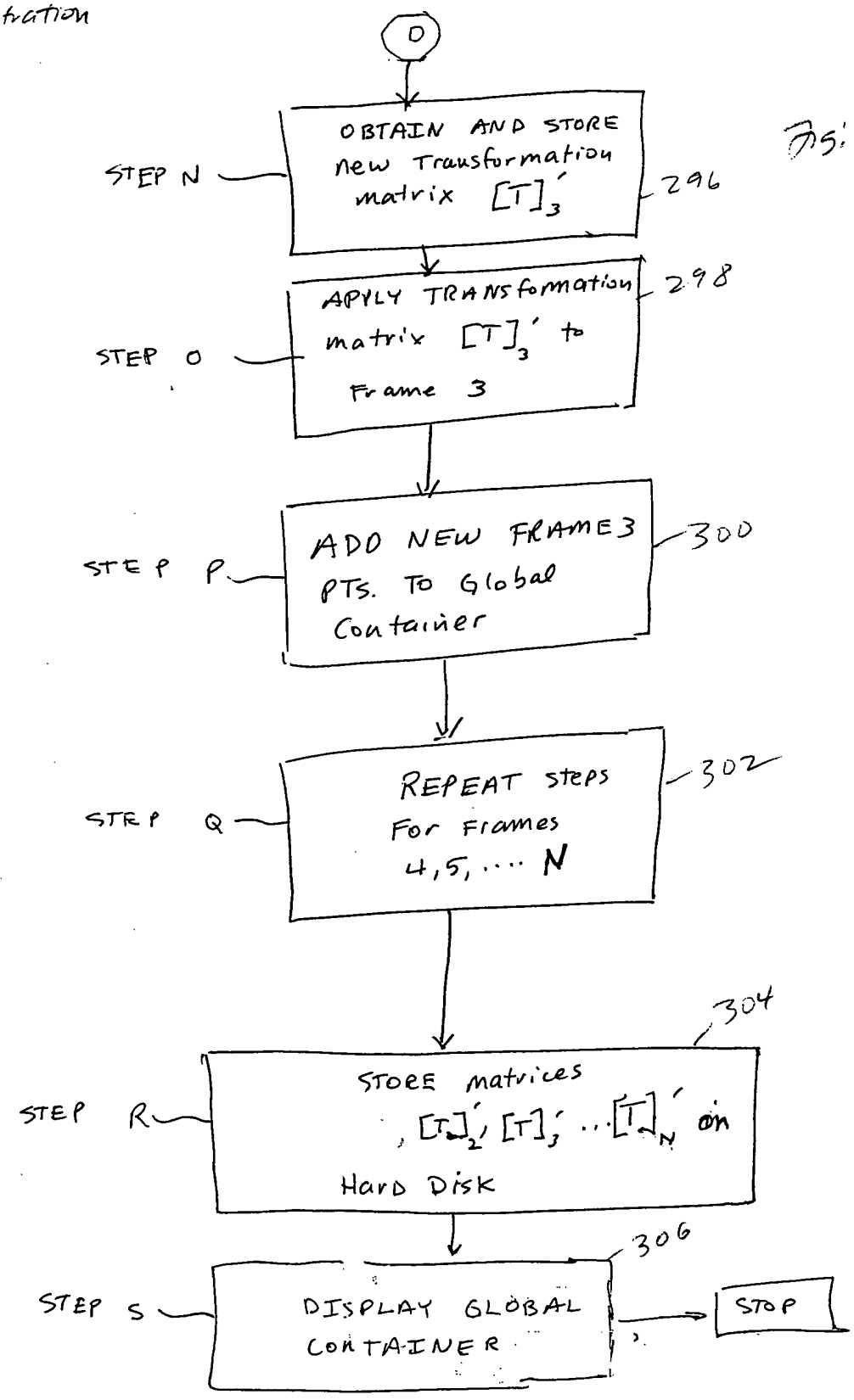
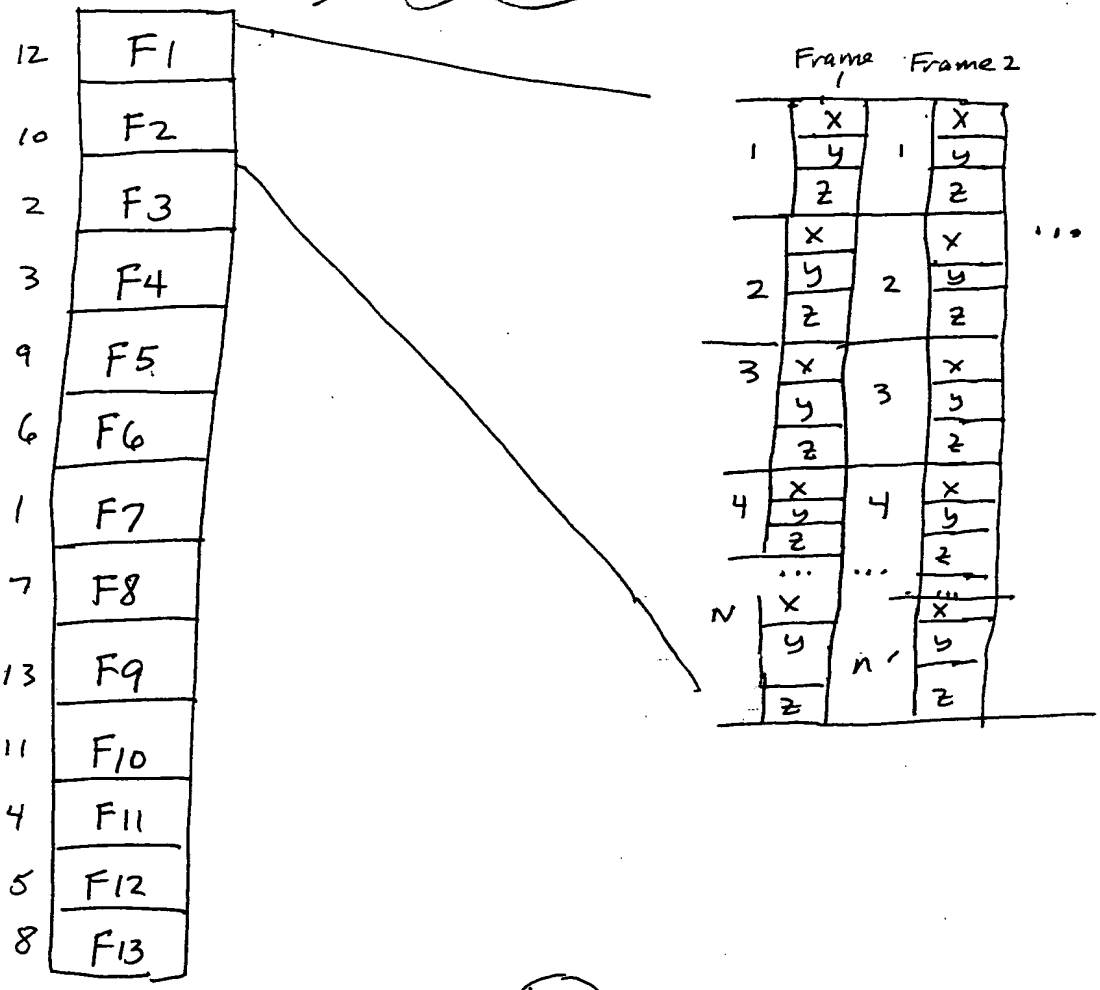


Fig. 48e

Fig. 49


12
F1
10
F2
2
F3
3
F4
9
F5
6
F6
1
F7
7
F8
13
F9
11
F10
4
F11
5
F12
8
F13
Frame 1
Frame 2
1
2
3
4
N
n'
x
y
z

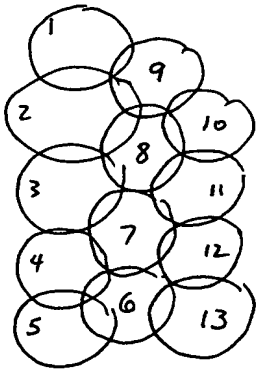

1
9
2
10
8
3
11
7
4
12
6
5
13

Fig. 50

Fig. 51

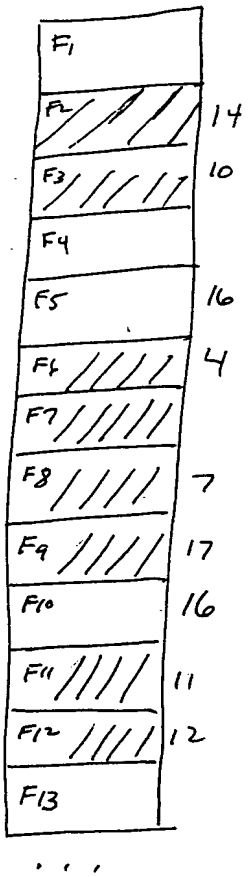


Fig. 52

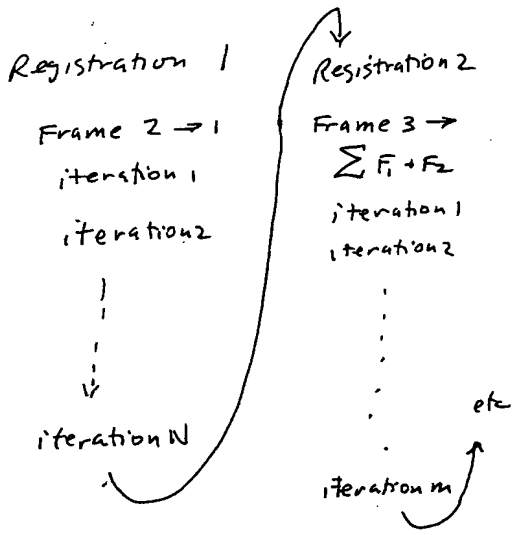


Fig. 53

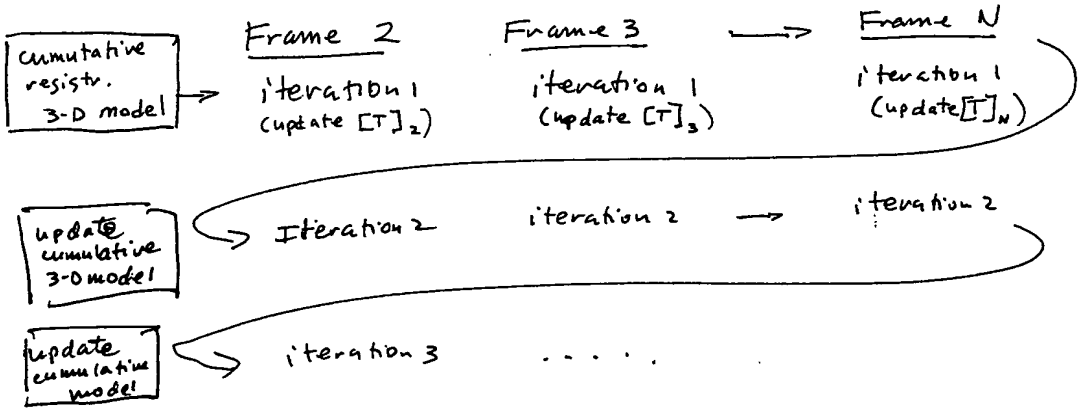


FIG. 54

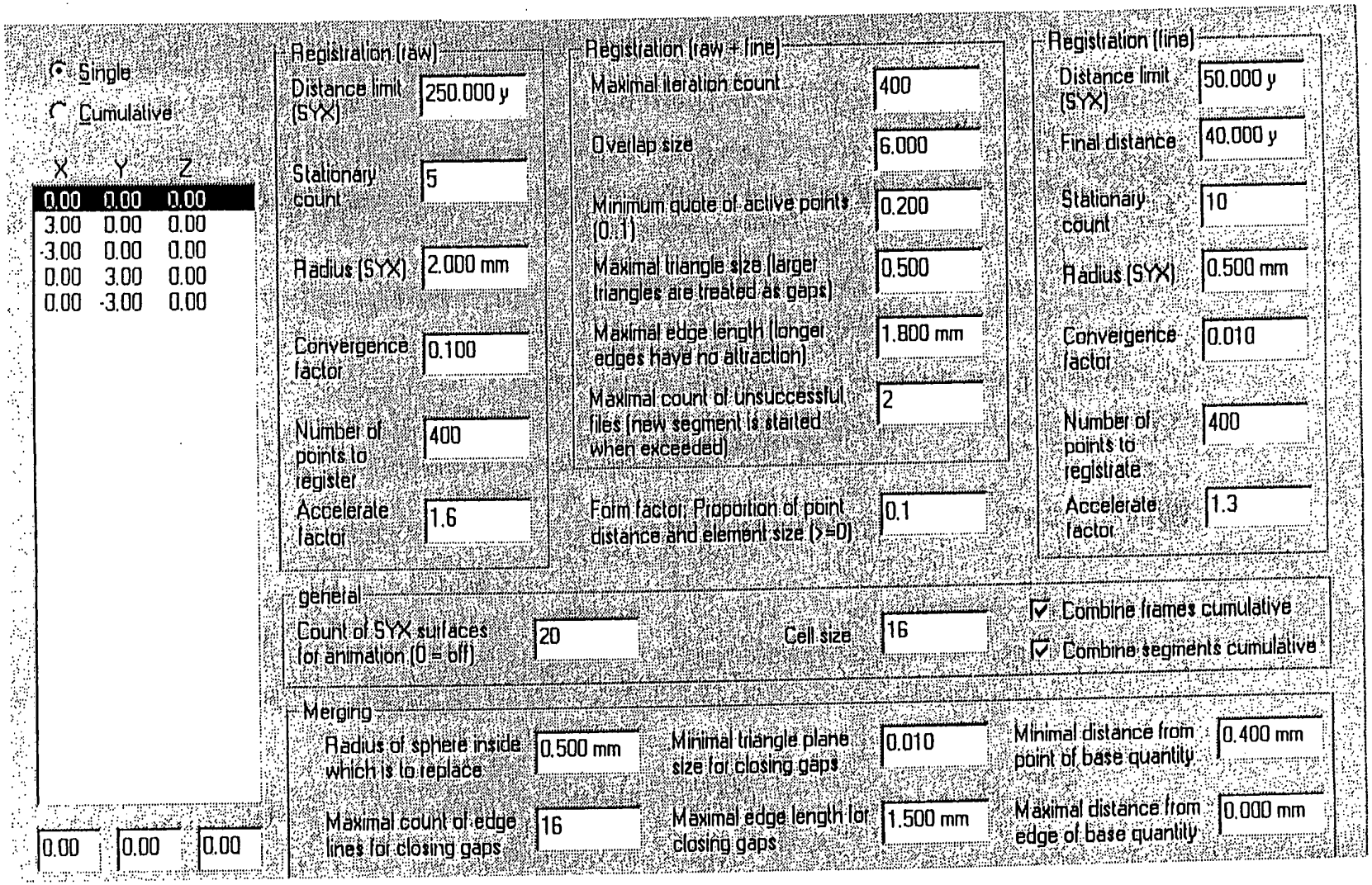
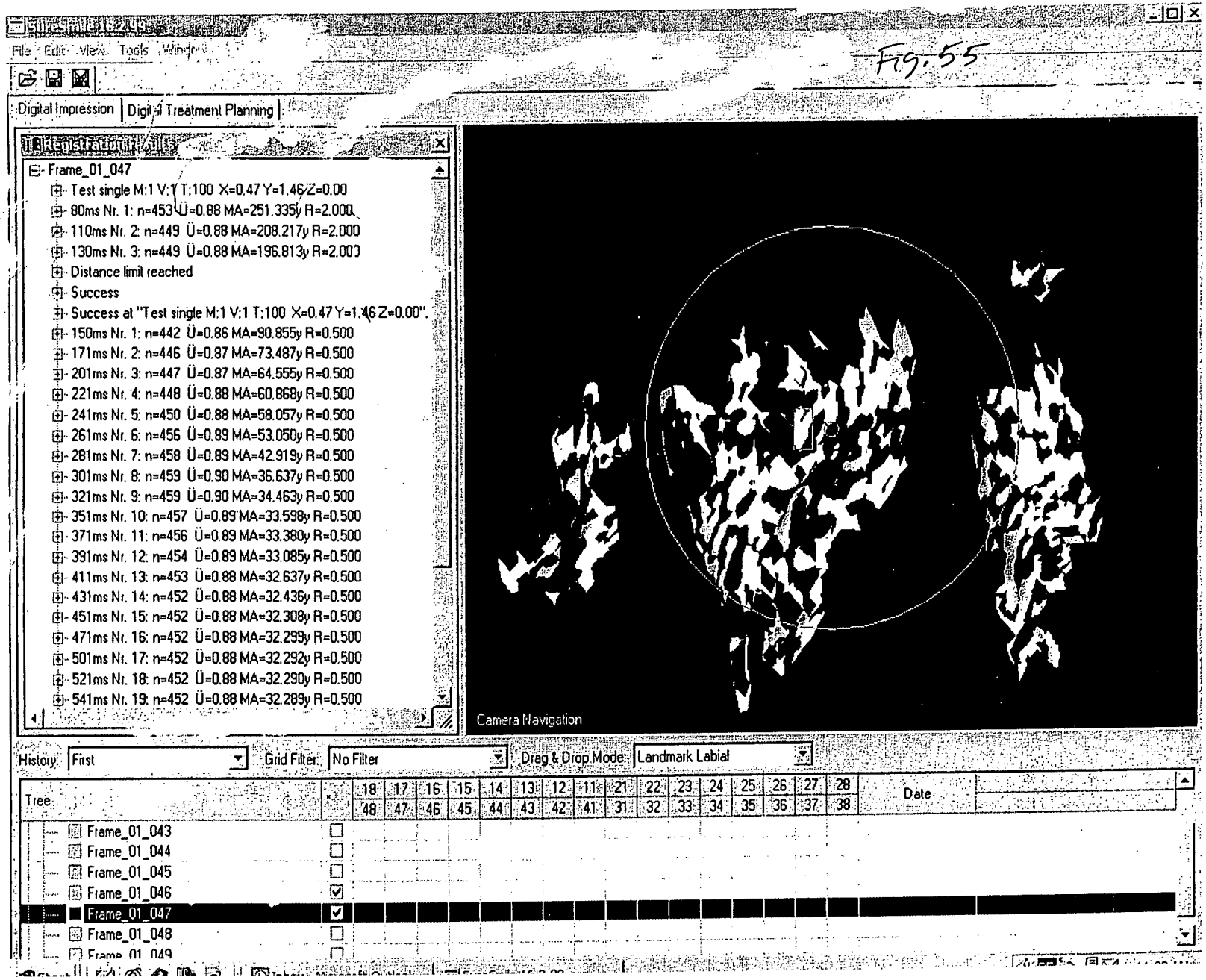
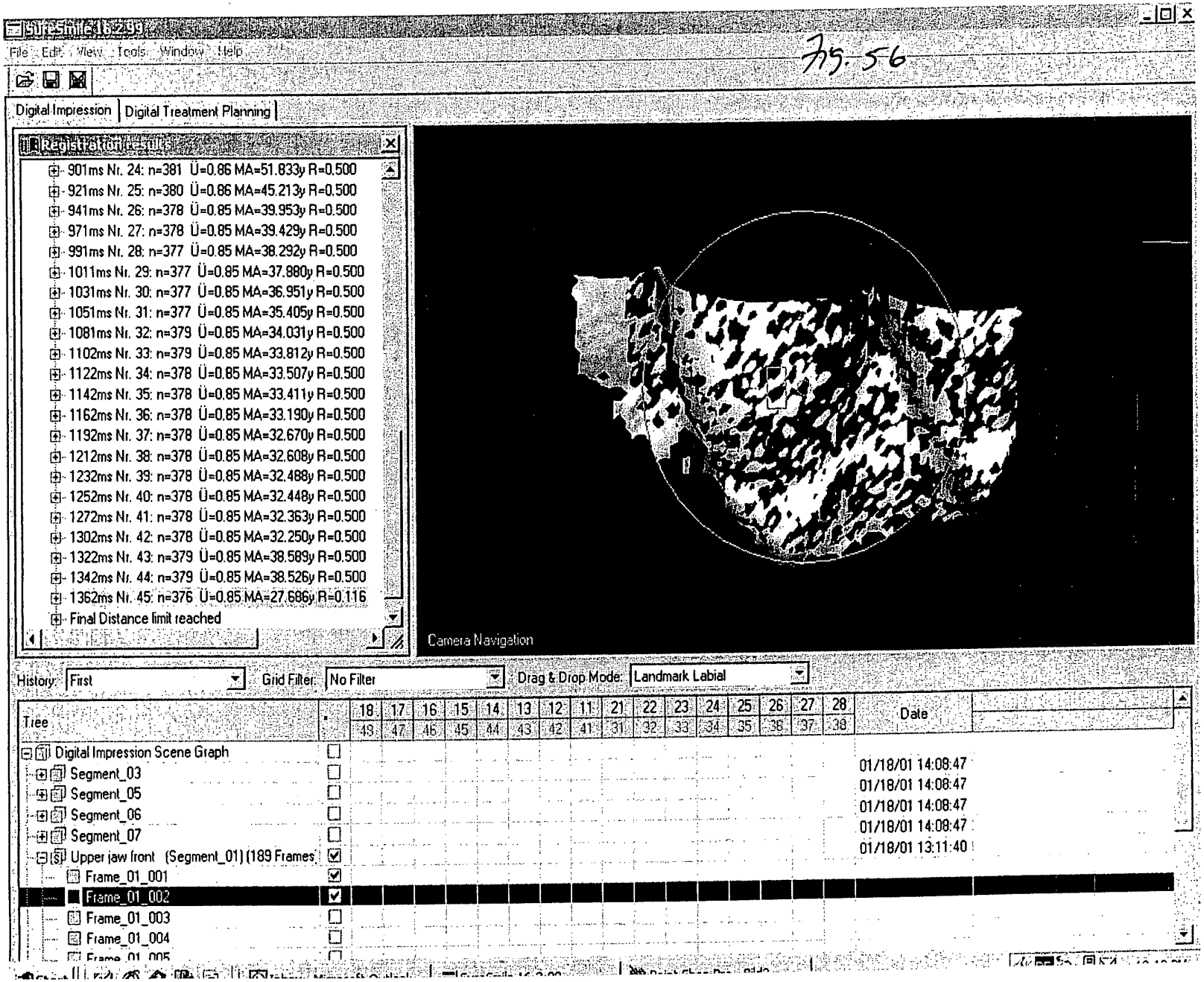
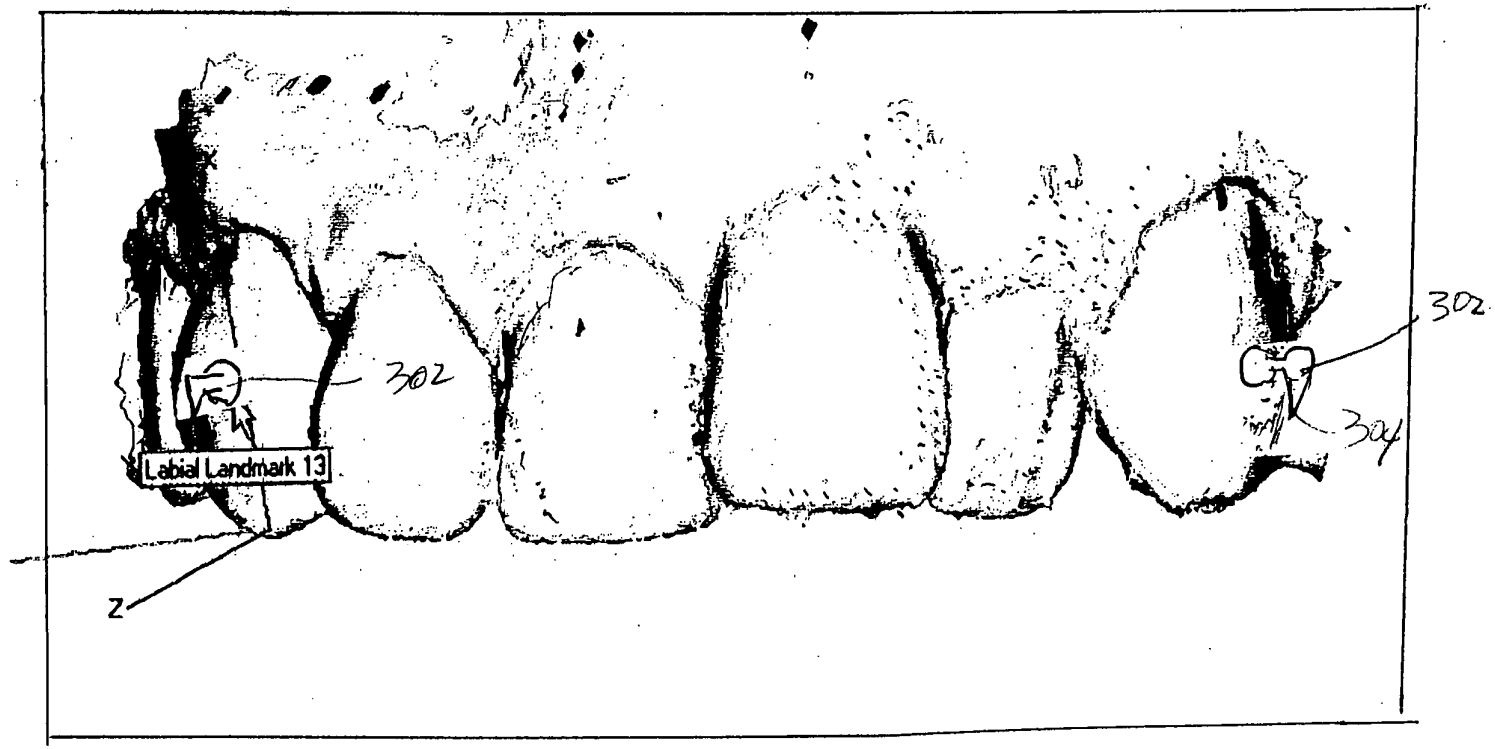

Single
Cumulative
X Y Z
0.00 0.00 0.00
3.00 0.00 0.00
-3.00 0.00 0.00
0.00 3.00 0.00
0.00 -3.00 0.00
0.00 0.00 0.00
Registration (raw)
Distance limit (SYX) 250.000 y
Stationary count 5
Radius (SYX) 2.000 mm
Convergence factor 0.100
Number of points to register 400
Accelerate factor 1.6
Registration (raw + fine)
Maximal iteration count 400
Overlap size 6.000
Minimum quote of active points (0..1) 0.200
Maximal triangle size (larger triangles are treated as gaps) 0.500
Maximal edge length (longer edges have no attraction) 1.800 mm
Maximal count of unsuccessful files (new segment is started when exceeded) 2
Form factor, Proportion of point distance and element size (>=0) 0.1
Registration (fine)
Distance limit (SYX) 50.000 y
Final distance 40.000 y
Stationary count 10
Radius (SYX) 0.500 mm
Convergence factor 0.010
Number of points to registrate 400
Accelerate factor 1.3
general
Count of SYX surfaces for animation (0 = off) 20
Cell size 16
Combine frames cumulative
Combine segments cumulative
Merging
Radius of sphere inside which is to replace 0.500 mm
Minimal triangle plane size for closing gaps 0.010
Minimal distance from point of base quantity 0.400 mm
Maximal count of edge lines for closing gaps 16
Maximal edge length for closing gaps 1.500 mm
Maximal distance from edge of base quantity 0.000 mm

Fig. 55


File Edit View Tools Window
Digital Impression
Digital Treatment Planning
Registration
Frame_01_047
Test single M:1 V:1 T:100 X=0.47 Y=1.46 Z=0.00
80ms Nr. 1: n=453 Ü=0.88 MA=251.335y R=2.000
110ms Nr. 2: n=449 Ü=0.88 MA=208.217y R=2.000
130ms Nr. 3: n=449 Ü=0.88 MA=196.813y R=2.000
Distance limit reached
Success
Success at "Test single M:1 V:1 T:100 X=0.47 Y=1.46 Z=0.00".
150ms Nr. 1: n=442 Ü=0.86 MA=90.855y R=0.500
171ms Nr. 2: n=446 Ü=0.87 MA=73.487y R=0.500
201ms Nr. 3: n=447 Ü=0.87 MA=64.555y R=0.500
221ms Nr. 4: n=448 Ü=0.88 MA=60.868y R=0.500
241ms Nr. 5: n=450 Ü=0.88 MA=58.057y R=0.500
261ms Nr. 6: n=456 Ü=0.89 MA=53.050y R=0.500
281ms Nr. 7: n=458 Ü=0.89 MA=42.919y R=0.500
301ms Nr. 8: n=459 Ü=0.90 MA=36.637y R=0.500
321ms Nr. 9: n=459 Ü=0.90 MA=34.463y R=0.500
351ms Nr. 10: n=457 Ü=0.89 MA=33.598y R=0.500
371ms Nr. 11: n=456 Ü=0.89 MA=33.380y R=0.500
391ms Nr. 12: n=454 Ü=0.89 MA=33.085y R=0.500
411ms Nr. 13: n=453 Ü=0.88 MA=32.637y R=0.500
431ms Nr. 14: n=452 Ü=0.88 MA=32.436y R=0.500
451ms Nr. 15: n=452 Ü=0.88 MA=32.308y R=0.500
471ms Nr. 16: n=452 Ü=0.88 MA=32.299y R=0.500
501ms Nr. 17: n=452 Ü=0.88 MA=32.292y R=0.500
521ms Nr. 18: n=452 Ü=0.88 MA=32.290y R=0.500
541ms Nr. 19: n=452 Ü=0.88 MA=32.289y R=0.500
Camera Navigation
History: First
Grid Filter: No Filter
Drag & Drop Mode: Landmark Labial
Tree
18 17 16 15 14 13 12 11 21 22 23 24 25 26 27 28
48 47 46 45 44 43 42 41 31 32 33 34 35 36 37 38
Date
Frame_01_043
Frame_01_044
Frame_01_045
Frame_01_046
Frame_01_047
Frame_01_048
Frame_01_049


File Edit View Tools Window Help
Digital Impression
Digital Treatment Planning
Registration results
901ms Nr. 24: n=381 Ü=0.86 MA=51.833y R=0.500
921ms Nr. 25: n=380 Ü=0.86 MA=45.213y R=0.500
941ms Nr. 26: n=378 Ü=0.85 MA=39.953y R=0.500
971ms Nr. 27: n=378 Ü=0.85 MA=39.429y R=0.500
991ms Nr. 28: n=377 Ü=0.85 MA=38.292y R=0.500
1011ms Nr. 29: n=377 Ü=0.85 MA=37.880y R=0.500
1031ms Nr. 30: n=377 Ü=0.85 MA=36.951y R=0.500
1051ms Nr. 31: n=377 Ü=0.85 MA=35.405y R=0.500
1081ms Nr. 32: n=379 Ü=0.85 MA=34.031y R=0.500
1102ms Nr. 33: n=379 Ü=0.85 MA=33.812y R=0.500
1122ms Nr. 34: n=378 Ü=0.85 MA=33.507y R=0.500
1142ms Nr. 35: n=378 Ü=0.85 MA=33.411y R=0.500
1162ms Nr. 36: n=378 Ü=0.85 MA=33.190y R=0.500
1192ms Nr. 37: n=378 Ü=0.85 MA=32.670y R=0.500
1212ms Nr. 38: n=378 Ü=0.85 MA=32.608y R=0.500
1232ms Nr. 39: n=378 Ü=0.85 MA=32.488y R=0.500
1252ms Nr. 40: n=378 Ü=0.85 MA=32.448y R=0.500
1272ms Nr. 41: n=378 Ü=0.85 MA=32.363y R=0.500
1302ms Nr. 42: n=378 Ü=0.85 MA=32.250y R=0.500
1322ms Nr. 43: n=379 Ü=0.85 MA=38.589y R=0.500
1342ms Nr. 44: n=379 Ü=0.85 MA=38.526y R=0.500
1362ms Nr. 45: n=376 Ü=0.85 MA=27.686y R=0.116
Final Distance limit reached
Camera Navigation
History First
Grid Filter: No Filter
Drag & Drop Mode: Landmark Labial
Tree
18 17 16 15 14 13 12 11 21 22 23 24 25 26 27 28
48 47 46 45 44 43 42 41 31 32 33 34 35 36 37 38
Date
Digital Impression Scene Graph
Segment_03
Segment_05
Segment_06
Segment_07
Upper jaw front (Segment_01) (189 Frames)
Frame_01_001
Frame_01_002
Frame_01_003
Frame_01_004
01/18/01 14:08:47
01/18/01 14:08:47
01/18/01 14:08:47
01/18/01 14:08:47
01/18/01 13:11:40



DRAG AND DROP MODE

Landmark Label

301

18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28

Upper jaw front (segment)

306 306

FIG. 57

Fig. 58A

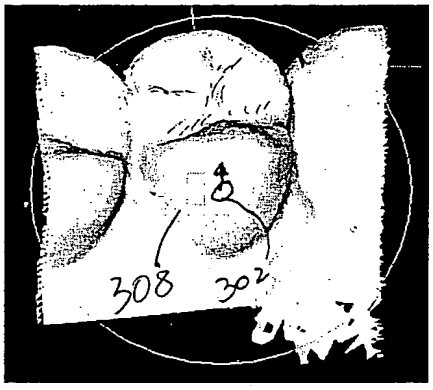


Fig. 58B

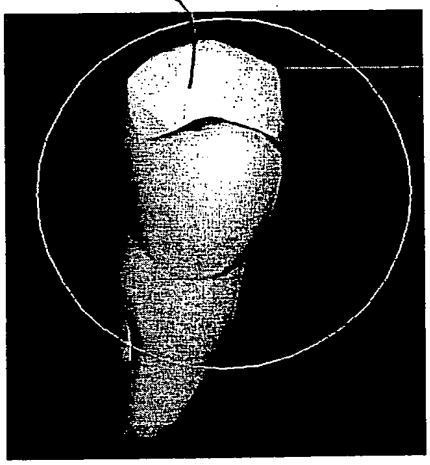


Fig. 58C

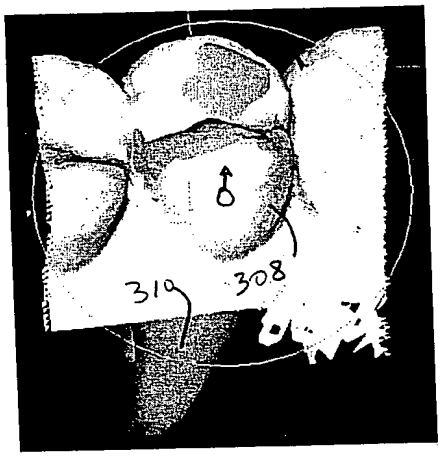
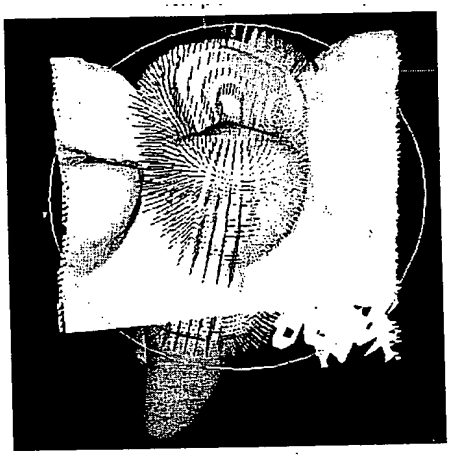


Fig. 58D



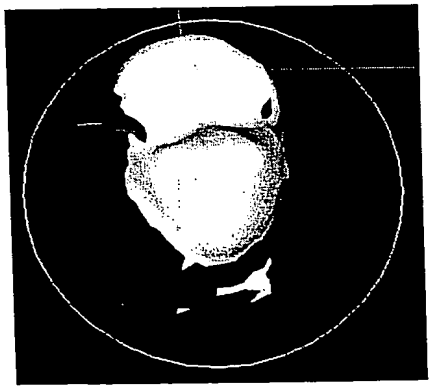
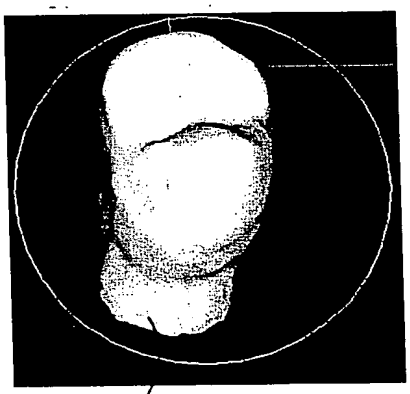


Fig. 58E



312 Fig. 58F

.a).

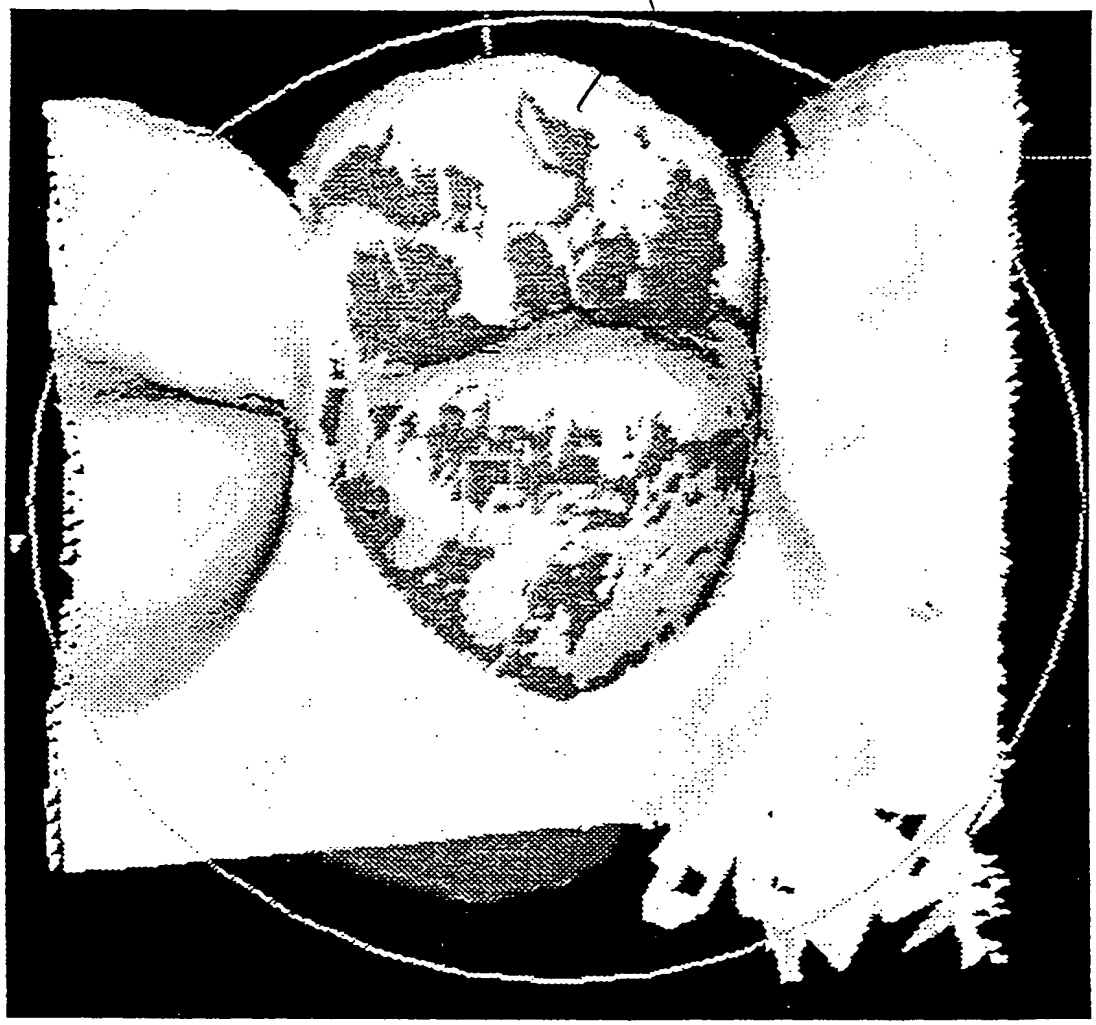
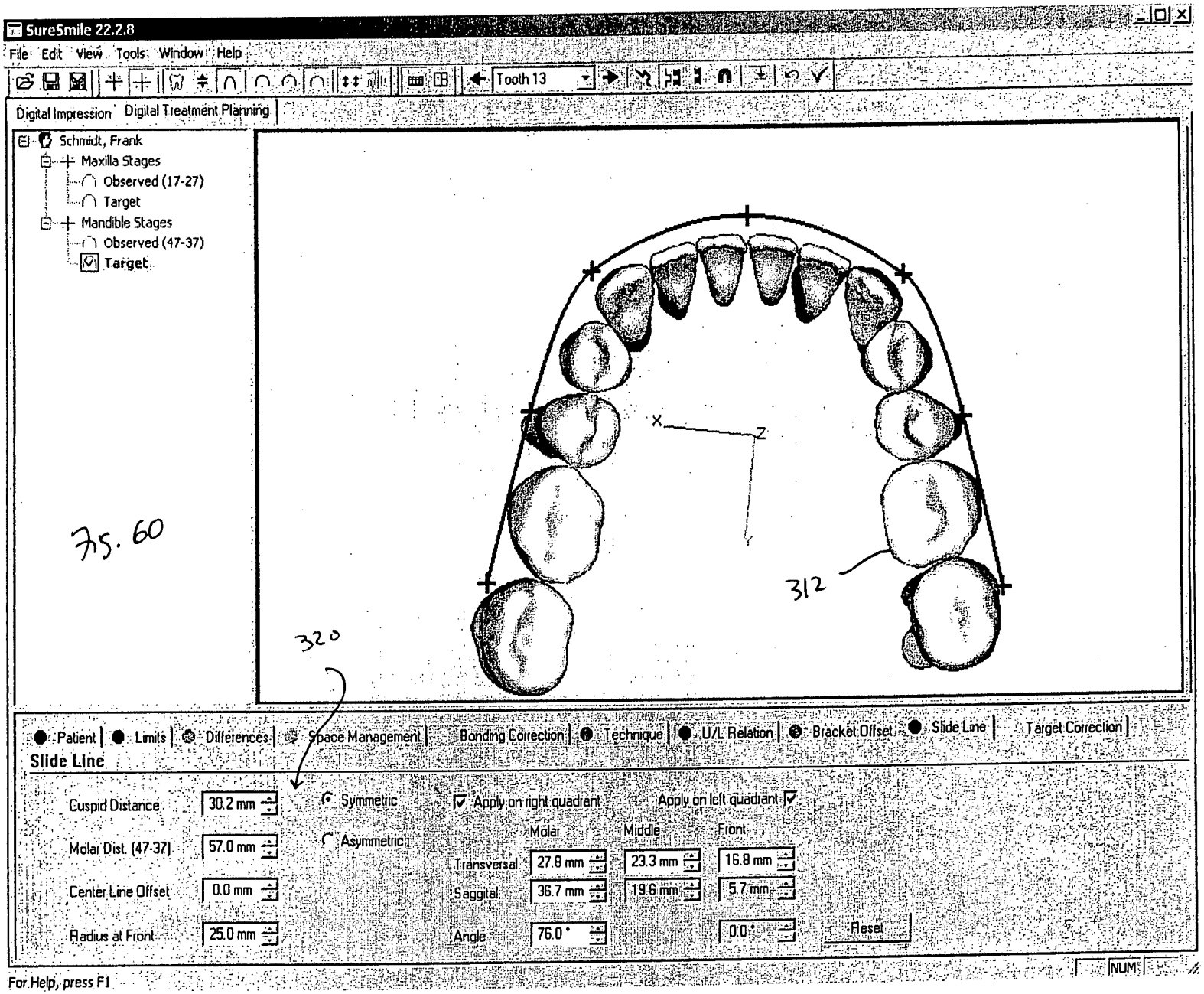
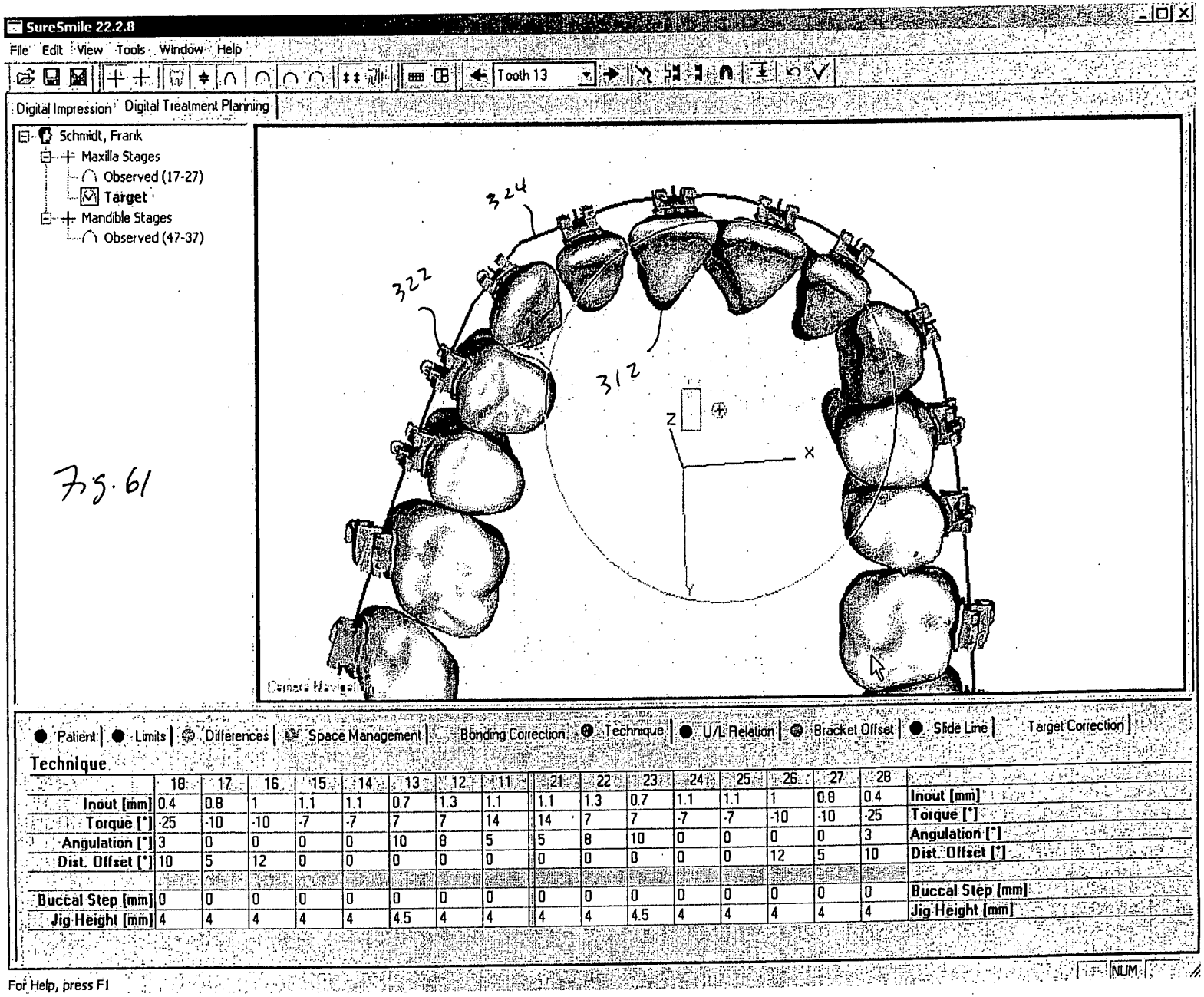


Fig. 59


SureSmile 22.2.8
File Edit View Tools Window Help
Tooth 13
Digital Impression
Digital Treatment Planning
Schmidt, Frank
Maxilla Stages
Observed (17-27)
Target
Mandible Stages
Observed (47-37)
Target
X
Z
312
320
75.60
Patient
Limits
Differences
Space Management
Bonding Correction
Technique
U/L Relation
Bracket Offset
Slide Line
Target Correction
Slide Line
Cuspid Distance
30.2 mm
Molar Dist. (47-37)
57.0 mm
Center Line Offset
0.0 mm
Radius at Front
25.0 mm
Symmetric
Asymmetric
Apply on right quadrant
Apply on left quadrant
Molar
Middle
Front
Transversal
27.8 mm
23.3 mm
16.8 mm
Sagittal
36.7 mm
19.6 mm
5.7 mm
Angle
76.0°
0.0°
Reset
For Help, press F1
NUM



	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28	
Inout [mm]	0.4	0.8	1	1.1	1.1	0.7	1.3	1.1	1.1	1.3	0.7	1.1	1.1	1	0.8	0.4	Inout [mm]
Torque [°]	-25	-10	-10	-7	-7	7	7	14	14	7	7	-7	-7	-10	-10	-25	Torque [°]
Angulation [°]	3	0	0	0	0	10	8	5	5	8	10	0	0	0	0	3	Angulation [°]
Dist. Offset [°]	10	5	12	0	0	0	0	0	0	0	0	0	0	12	5	10	Dist. Offset [°]
Buccal Step [mm]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Buccal Step [mm]
Jig Height [mm]	4	4	4	4	4	4.5	4	4	4	4	4.5	4	4	4	4	4	Jig Height [mm]

Fig. 61

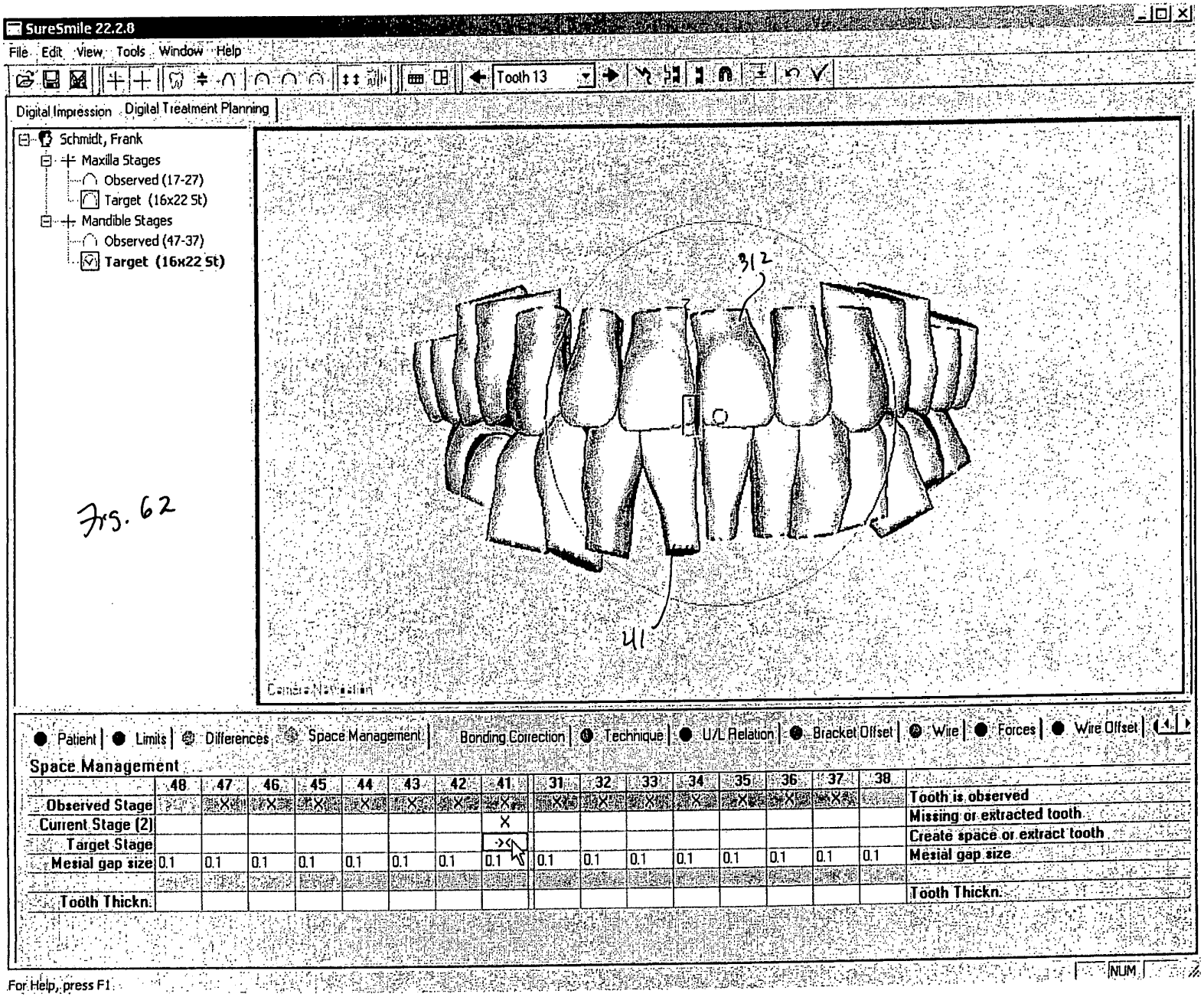

SureSmile 22.2.8
File Edit View Tools Window Help
Tooth 13
Digital Impression
Digital Treatment Planning
Schmidt, Frank
Maxilla Stages
Observed (17-27)
Target (16x22 St)
Mandible Stages
Observed (47-37)
Target (16x22 St)
312
41
Patient
Limits
Differences
Space Management
Bonding Correction
Technique
U/L Relation
Bracket Offset
Wire
Forces
Wire Offset
Space Management
48 47 46 45 44 43 42 41 31 32 33 34 35 36 37 38
Observed Stage
Current Stage (2)
Target Stage
Mesial gap size
Tooth Thickn.
Tooth is observed
Missing or extracted tooth
Create space or extract tooth
Mesial gap size
Tooth Thickn.
For Help, press F1
NUM

Fig. 62

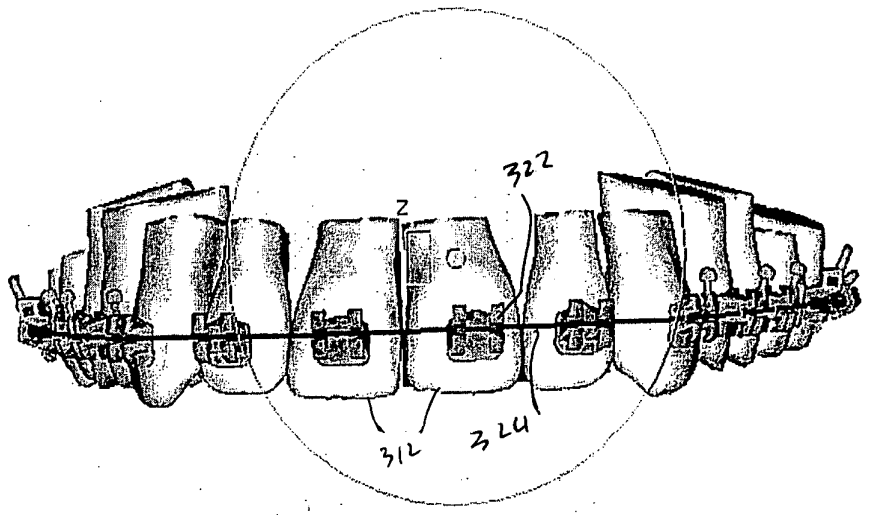
SureSmile 22.2.8

File Edit View Tools Window Help

Tooth 13

Digital Impression | Digital Treatment Planning

- Schmidt, Frank
  - Maxilla Stages
    - Observed (17-27)
    - Target
  - Mandible Stages
    - Observed (47-37)



Camera Navigation

FIG. 63

Patient | Limits | Differences | Space Management | Bonding Correction | Technique | U/L Relation | Bracket Offset | Slide Line | Target Correction

Technique

	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28	
Inout [mm]	0.4	0.8	1	1.1	1.1	0.7	1.3	1.1	1.1	1.3	0.7	1.1	1.1	1	0.8	0.4	Inout [mm]
Torque [°]	-25	-10	-10	-7	-7	7	7	14	14	7	7	-7	-7	-10	-10	-25	Torque [°]
Angulation [°]	3	0	0	0	0	10	8	5	5	8	10	0	0	0	0	3	Angulation [°]
Dist. Offset [°]	10	5	12	0	0	0	0	0	0	0	0	0	0	12	5	10	Dist. Offset [°]
Buccal Step [mm]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Buccal Step [mm]
Jig Height [mm]	4	4	4	4	4	4.5	4	4	4	4	4.5	4	4	4	4	4	Jig Height [mm]

NUM

For Help, press F1

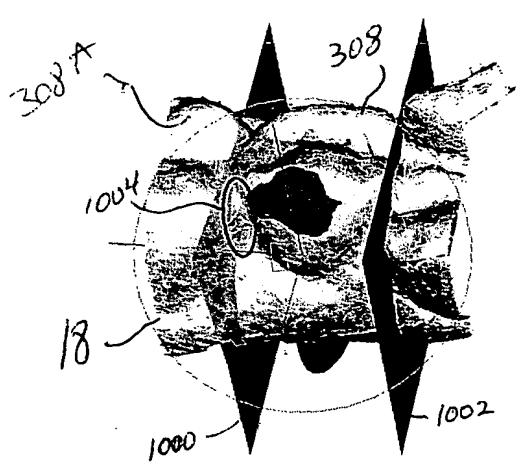


Fig. 64A

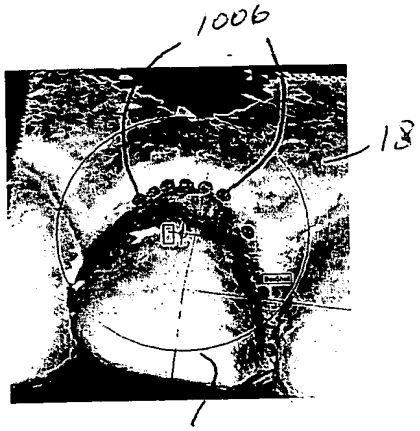


Fig. 64B

Fig. 64C

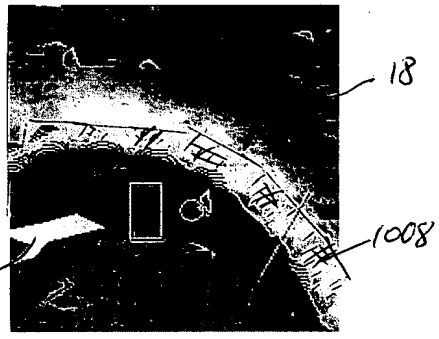


Fig. 64D

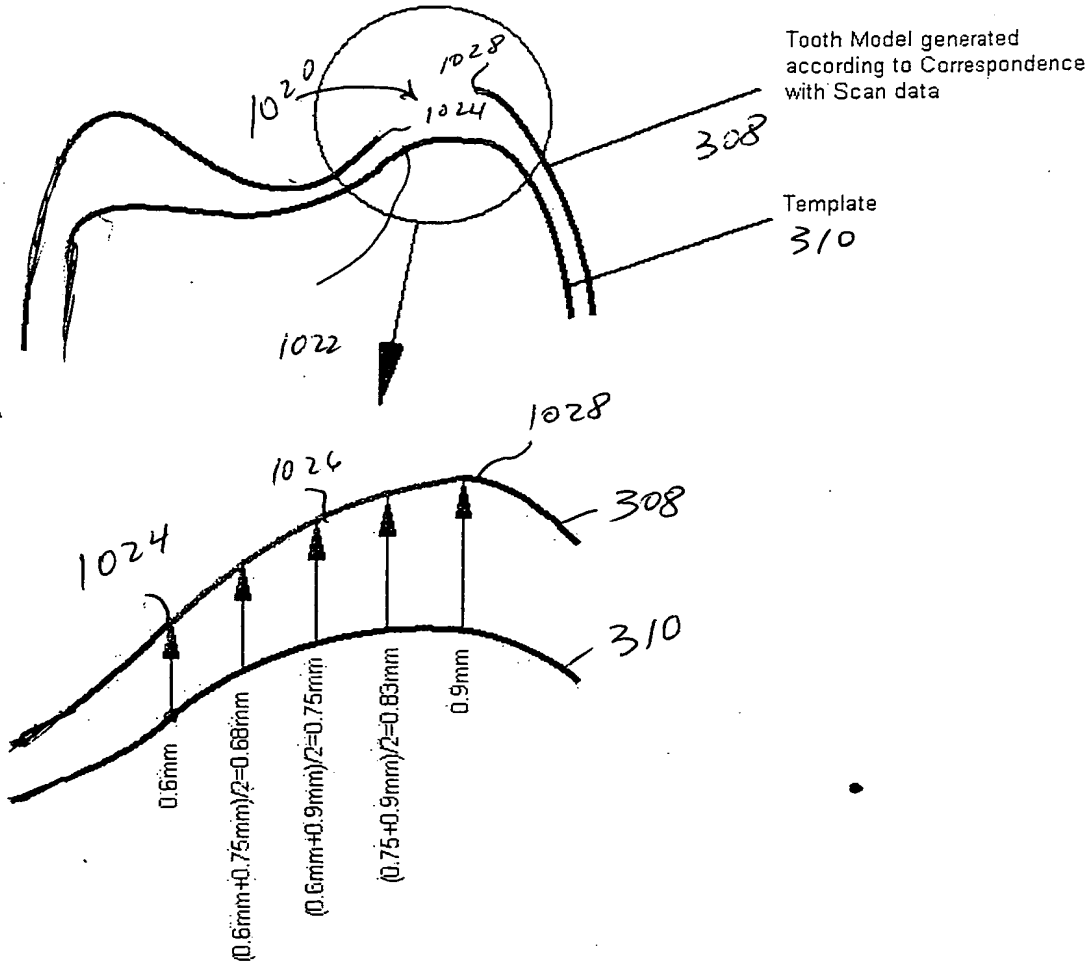

1020
1028
1024
Tooth Model generated according to Correspondence with Scan data
308
Template
310
1022
1028
1026
1024
308
310
0.6mm
(0.6mm+0.75mm)/2=0.68mm
(0.6mm+0.9mm)/2=0.75mm
(0.75+0.9mm)/2=0.83mm
0.9mm

Fig. 65